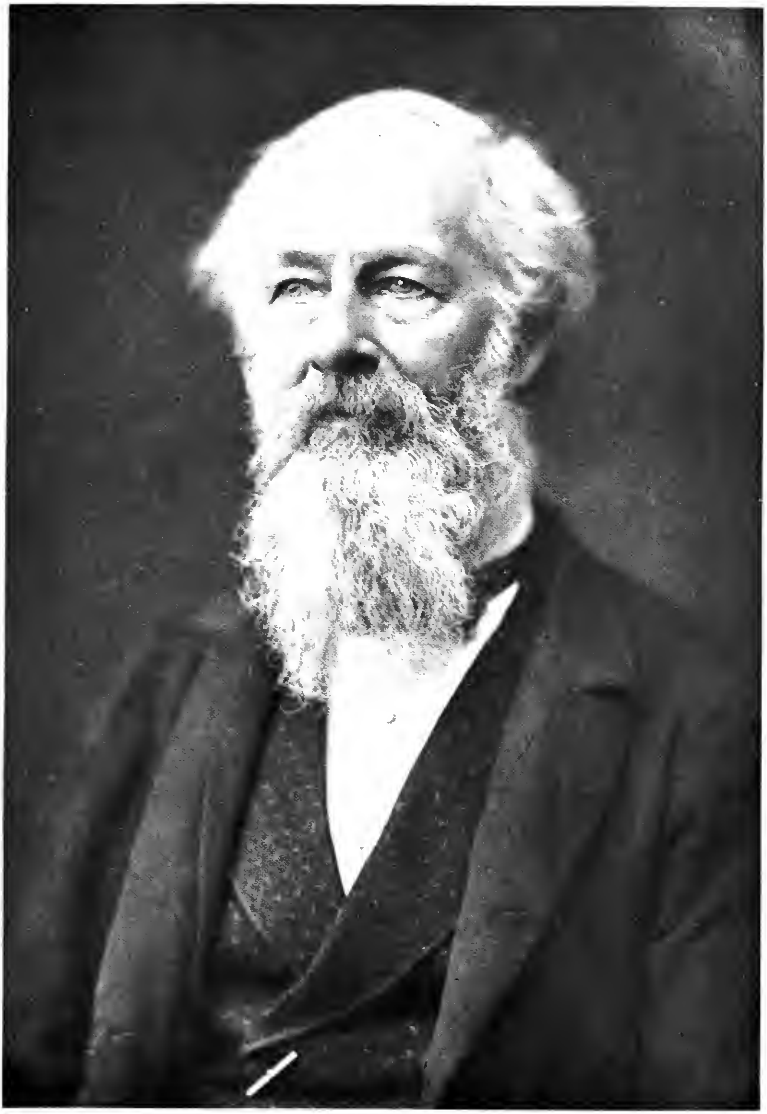


William P. Marshall

SECRETARY, I. MECH. E., 1849–1878.

(*Deceased 1906.*)

A

THE INSTITUTION

OF

MECHANICAL ENGINEERS.

ESTABLISHED 1847.

PROCEEDINGS.

1906.

PARTS 1–2.

PUBLISHED BY THE INSTITUTION,

STOREY'S GATE, ST. JAMES'S PARK, WESTMINSTER, S.W.

CONTENTS.

1906.

PARTS 1-2.

The Institution of Mechanical Engineers.

PAST-PRESIDENTS.

George Stephenson, 1847–48. (*Deceased* 1848.)

Robert Stephenson, F.R.S., 1849–53. (*Deceased* 1859.)

Sir William Fairbairn, Bart., LL.D., F.R.S., 1854–55. (*Deceased* 1874.)

Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., 1856–57, 1866. (*Deceased* 1887.)

John Penn, F.R.S., 1858–59, 1867–68. (*Deceased* 1878.)

James Kennedy, 1860. (*Deceased* 1886.)

The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., 1861–62, 1869. (*Deceased* 1900.)

Robert Napier, 1863–65. (*Deceased* 1876.)

John Ramsbottom, 1870–71. (*Deceased* 1897.)

Sir William Siemens, D.C.L., LL.D., F.R.S., 1872–73. (*Deceased* 1883.)

Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S., 1874–75. (*Deceased* 1903.)

Thomas Hawksley, F.R.S., 1876–77. (*Deceased* 1893.)

John Robinson, 1878–79. (*Deceased* 1902.)

Edward A. Cowper, 1880–81. (*Deceased* 1893.)

Percy G. B. Westmacott, 1882–83.

Sir Lowthian Bell, Bart., LL.D., F.R.S., 1884. (*Deceased* 1904.)

Jeremiah Head, 1885–86. (*Deceased* 1899.)

Sir Edward H. Carbutt, Bart., 1887–88. (*Deceased* 1905.)

Charles Cochrane, 1889. (*Deceased* 1898.)

Joseph Tomlinson, 1890–91. (*Deceased* 1894.)

Sir William Anderson, K.C.B., D.C.L., F.R.S., 1892–93. (*Deceased* 1898.)

Sir Alexander B. W. Kennedy, LL.D., F.R.S., 1894–95.

E. Windsor Richards, 1896–97.

Samuel Waite Johnson, 1898.

Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S., 1899–1900.

William H. Maw, 1901–02.

J. Hartley Wicksteed, 1903–04.

The Institution of Mechanical Engineers.

OFFICERS.

1906.

PRESIDENT.

Edward P. Martin, ... Abergavenny.

PAST-PRESIDENTS.

Samuel Waite Johnson, ... Nottingham.
Sir Alexander B. W. Kennedy, LL.D., F.R.S., ... London.
William H. Maw, ... London.
E. Windsor Richards, ... Caerleon.
Percy G. B. Westmacott, ... Ascot.
Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S., .. London.
J. Hartley Wicksteed, ... Leeds.

VICE-PRESIDENTS.

John A. F. Aspinall, ... Manchester.
Edward B. Ellington, ... London.
Arthur Keen, ... Birmingham.
Sir William T. Lewis, Bart., ... Aberdare.
T. Hurry Riches, ... Cardiff.
A. Tannett-Walker, ... Leeds.

MEMBERS OF COUNCIL.

Sir Benjamin Baker, K.C.B., K.C.M.G., LL.D., D.Sc., F.R.S., London.
Sir J. Wolfe Barry, K.C.B., LL.D., F.R.S., ... London.
Henry Chapman, ... London.
George J. Churchward, ... Swindon.
Henry Davey, ... London.
H. F. Donaldson, ... Woolwich.
H. Graham Harris, ... London.
Edward Hopkinson, D.Sc., ... Manchester.
J. Rossiter Hoyle, ... Sheffield.
Henry A. Ivatt, ... Doncaster.
Henry Lea, ... Birmingham.
Michael Longridge, ... Manchester.
The Right Hon. William J. Pirrie, LL.D., ... Belfast.
Sir Thomas Richardson, ... Hartlepool.
John F. Robinson, ... London.
Mark H. Robinson, ... Rugby.
James Rowan, ... Glasgow.
John W. Spencer, ... Newcastle-on-Tyne.
Sir John I. Thornycroft, LL.D., F.R.S., ... London.
John Tweedy, ... Newcastle-on-Tyne.
Henry H. West, ... Liverpool.

HON. TREASURER.

Frederick William Ellis.

AUDITOR.

Robert A. McLean, F.C.A.

SECRETARY.

Edgar Worthington,
The Institution of Mechanical Engineers,
Storey's Gate, St. James's Park, Westminster, S.W.
Telegraphic address :—*Mech, London.* Telephone :—*Westminster,* 264.

THE INSTITUTION OF MECHANICAL ENGINEERS.

Memorandum of Association.

August 1878.

1st. The name of the Association is "The Institution of Mechanical Engineers."

2nd. The Registered Office of the Association will be situate in England.

3rd. The objects for which the Association is established are :—

(a.) To promote the science and practice of Mechanical Engineering and all branches of mechanical construction, and to give an impulse to inventions likely to be useful to the Members of the Institution and to the community at large.

(b.) To enable Mechanical Engineers to meet and to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of mechanical science, and the publication and communication of information on such subjects.

(c.) To acquire and dispose of property for the purposes aforesaid.

(d.) To do all other things incidental or conducive to the attainment of the above objects or any of them.

4th. The income and property of the Association, from whatever source derived, shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly, by way of dividend, bonus, or otherwise howsoever, by way of profit to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them: Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any Member of the Association, or other person, in return for any services rendered to the Association, or prevent the giving of privileges to the Members of the Association in attending the meetings of the Association, or prevent the borrowing of money (under such powers as the Association and the Council thereof may possess) from any Member of the Association, at a rate of interest not greater than five per cent. per annum.

5th. The fourth paragraph of this Memorandum is a condition on which a licence is granted by the Board of Trade to the Association in pursuance of Section 23 of the Companies Act 1867. For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which shall be duly observed by the Association.

6th. If the Association act in contravention of the fourth paragraph of this Memorandum, or of any such further conditions, the liability of every Member of the Council shall be unlimited; and the liability of every Member of the Association who has received any such dividend, bonus, or other profit as aforesaid, shall likewise be unlimited.

7th. Every Member of the Association undertakes to contribute to the Assets of the Association in the event of the same being wound up during the time that he is a Member, or within one

year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a Member, and of the costs, charges, and expenses for winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding Five Shillings, or in case of his liability becoming unlimited such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

8th. If upon the winding up or dissolution of the Association there remains, after the satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the Members of the Association, but shall be given or transferred to some other Institution or Institutions having objects similar to the objects of the Association, to be determined by the Members of the Association at or before the time of dissolution; or in default thereof, by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter.

Articles of Association.

February 1893.

(*Article* 23 *revised March* 1902.)

INTRODUCTION.

Whereas an Association called "The Institution of Mechanical Engineers" existed from 1847 to 1878 for objects similar to the objects expressed in the Memorandum of Association of the Association (hereinafter called "the Institution") to which these Articles apply;

And whereas the Institution was formed in 1878 for furthering and extending the objects of the former Institution, by a registered Association, under the Companies Acts 1862 and 1867;

And whereas terms used in these Articles are intended to have the same respective meanings as they have when used in those Acts, and words implying the singular number are intended to include the plural number, and *vice versâ*;

Now therefore it is hereby agreed as follows:—

CONSTITUTION.

1. For the purpose of registration the number of members of the Institution is unlimited.

MEMBERS, ASSOCIATE MEMBERS, GRADUATES, ASSOCIATES, AND HONORARY LIFE MEMBERS.

2. The present Members of the Institution, and such other persons as shall be admitted in accordance with these Articles, and none others, shall be Members of the Institution, and be entered on the register as such.

3. Any person may become a Member of the Institution who shall be qualified and elected as hereinafter mentioned, and shall agree to become such Member, and shall pay the entrance fee and first subscription accordingly.

4. The qualification of Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

5. The election of Members shall be conducted as prescribed by the By-laws from time to time in force, as provided by the Articles.

6. In addition to the persons already admitted as Graduates, Associates, and Honorary Life Members respectively, the Institution may admit such persons as may be qualified and elected in that behalf as Associate Members, Graduates, Associates, and Honorary Life Members respectively of the Institution, and may confer upon them such privileges as shall be prescribed by the By-laws from time to time in force, as provided by the Articles: provided that no Associate Member, Graduate, Associate, or Honorary Life Member shall be deemed to be a Member within the meaning of the Articles.

7. The qualification and mode of election of Associate Members, Graduates, Associates, and Honorary Life Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

8. The rights and privileges of every Member, Associate Member, Graduate, Associate, or Honorary Life Member shall be personal to himself, and shall not be transferable or transmissible by his own act or by operation of law.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. The Entrance Fees and Subscriptions of Members, Associate Members, Graduates, and Associates shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

EXPULSION.

10. If any Member, Associate Member, Graduate, or Associate shall leave his subscription in arrear for two years, and shall fail to pay such arrears within three months after a written application has been sent to him by the Secretary, his name may be struck off the register by the Council at any time afterwards, and he shall thereupon cease to have any rights as a Member, Associate Member, Graduate, or Associate, but he shall nevertheless continue liable to pay the arrears of subscription due at the time of his name being so struck off: provided always that this regulation shall not be construed to compel the Council to remove any name, if they shall be satisfied the same ought to be retained.

11. The Council may refuse to continue to receive the subscriptions of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall in the opinion of the Council have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution; and may remove his name from the register, and he shall thereupon cease to be a Member, Associate Member, Graduate, or Associate (as the case may be) of the Institution.

GENERAL MEETINGS.

12. The General Meetings shall consist of the Ordinary Meetings, the Annual General Meeting, and of Special Meetings as hereinafter defined.

13. The Annual General Meeting shall take place in London in one of the first four months of every year. The Ordinary Meetings shall take place at such times and places as the Council shall determine.

14. A Special Meeting may be convened at any time by the Council, and shall be convened by them whenever a requisition signed by twenty Members or Associate Members of the Institution,

specifying the object of the Meeting, is left with the Secretary. If for fourteen days after the delivery of such requisition a Meeting be not convened in accordance therewith, the Requisitionists or any twenty Members or Associate Members of the Institution may convene a Special Meeting in accordance with the requisition. All Special Meetings shall be held in London.

15. Seven clear days' notice of every Meeting, specifying generally the nature of any special business to be transacted at any Meeting, shall be given to every person on the register of the Institution, except as provided by Article 35, and no other special business shall be transacted at such Meeting; but the non-receipt of such notice shall not invalidate the proceedings of such Meeting. No notice of the business to be transacted (other than such ballot lists as may be requisite in case of elections) shall be required in the absence of special business.

16. Special business shall include all business for transaction at a Special Meeting, and all business for transaction at every other Meeting, with the exception of the reading and confirmation of the Minutes of the previous Meeting, the election of Members, Associate Members, Graduates, and Associates, and the reading and discussion of communications as prescribed by the By-laws, or by any regulations of the Council made in accordance with the By-laws.

PROCEEDINGS AT GENERAL MEETINGS.

17. Twenty Members or Associate Members shall constitute a quorum for the purpose of a Meeting other than a Special Meeting. Thirty Members or Associate Members shall constitute a quorum for the purpose of a Special Meeting.

18. If within thirty minutes after the time fixed for holding the Meeting a quorum is not present, the Meeting shall be dissolved, and all matters which might, if a quorum had been present, have been done at a Meeting (other than a Special Meeting) so dissolved, may forthwith be done on behalf of the Meeting by the Council.

19. The President shall be Chairman at every Meeting, and in his absence one of the Vice-Presidents; and in the absence of all Vice-Presidents a Member of Council shall take the chair; and if no Member of Council be present and willing to take the chair, the Meeting shall elect a Chairman.

20. The decision of a General Meeting shall be ascertained by show of hands, unless, after the show of hands, a poll is forthwith demanded; and by a poll, when a poll is thus demanded. The manner of taking a show of hands or a poll shall be in the discretion of the Chairman; and an entry in the Minutes, signed by the Chairman, shall be sufficient evidence of the decision of the General Meeting. Each Member and Associate Member shall have one vote and no more. In case of equality of votes the Chairman shall have a second or casting vote: provided that this Article shall not interfere with the provisions of the By-laws as to election by ballot.

21. The acceptance or rejection of votes by the Chairman shall be conclusive for the purpose of the decision of the matter in respect of which the votes are tendered: provided that the Chairman may review his decision at the same Meeting, if any error be then pointed out to him.

BY-LAWS.

22. The By-laws set forth in the schedule to these Articles, and such altered and additional By-laws as shall be substituted or added as hereinafter mentioned, shall regulate all matters by the Articles left to be prescribed by the By-laws, and all matters which consistently with the Articles shall be made the subject of By-laws. Alterations in, and additions to, the By-laws, may be made only by resolution of the Members and Associate Members at an Annual General Meeting, after notice of the proposed alteration or addition has been announced at the previous Ordinary Meeting, and not otherwise.

COUNCIL.

23. The Council of the Institution shall be chosen from the Members only, and shall consist of one President, six Vice-Presidents, twenty-one ordinary Members of Council, and of the Past-Presidents. The President, two Vice-Presidents, and seven Members of Council (other than Past-Presidents), shall retire at each Annual General Meeting, but shall be eligible for re-election. The Vice-Presidents and Members of Council to retire each year shall, unless the Council agree otherwise among themselves, be chosen from those who have been longest in office, and in cases of equal seniority shall be determined by ballot.

24. The election of a President, Vice-Presidents, and Members of Council, to supply the place of those retiring at the Annual General Meeting, shall be conducted in such manner as shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

25. The Council may supply any casual vacancy in the Council (including any casual vacancy in the office of President) which shall occur between one Annual General Meeting and another; and the President, Vice-Presidents, or Members of Council so appointed by the Council shall retire at the succeeding Annual General Meeting. Vacancies not filled up at any such Meeting shall be deemed to be casual vacancies within the meaning of this Article.

OFFICERS.

26. The Treasurer, Secretary, and other employés of the Institution shall be appointed and removed in the manner prescribed by the By-laws from time to time in force, as provided by the Articles. Subject to the express provisions of the By-laws, the officers and servants of the Institution shall be appointed and removed by the Council.

27. The powers and duties of the officers of the Institution shall, subject to any express provision in the By-laws, be determined by the Council.

POWERS AND PROCEDURE OF COUNCIL.

28. The Council may regulate their own procedure, and delegate any of their powers and discretions to any one or more of their body, and may determine their own quorum: if no other number is prescribed, three members of Council shall form a quorum.

29. The Council shall manage the property, proceedings, and affairs of the Institution, in accordance with the By-laws from time to time in force.

30. The Treasurer may, with the consent of the Council, invest in the name of the Institution any moneys not immediately required for the purposes of the Institution in or upon any of the following investments (that is to say):—

(A) The Public Funds, or Government Stocks of the United Kingdom, or of any Foreign or Colonial Government guaranteed by the Government of the United Kingdom.

(B) Real or Leasehold Securities, or in the purchase of real or leasehold properties in Great Britain or Ireland.

(C) Debentures, Debenture Stock, or Guaranteed or Preference Stock, of any Company incorporated by special Act of Parliament, the ordinary Shareholders whereof shall at the time of such investment be in actual receipt of half-yearly or yearly dividends.

(D) Stocks, Shares, Debentures, or Debenture Stock of any Railway, Canal, or other Company, the undertaking whereof is leased to any Railway Company at a fixed or fixed minimum rent.

(E) Stocks, Shares, or Debentures of any East Indian Railway or other Company, which shall receive a contribution from His Majesty's East Indian Government of a fixed annual percentage on their capital, or be guaranteed a fixed annual dividend by the same Government.

(F) The security of rates levied by any corporate body empowered to borrow money on the security of rates, where such borrowing has been duly authorised by Act of Parliament.

31. The Council may, with the authority of a resolution of the Members and Associate Members in General Meeting, borrow moneys for the purposes of the Institution on the security of the property of the Institution, or otherwise at their discretion.

32. No act done by the Council, whether *ultra vires* or not, which shall receive the express or implied sanction of the Members and Associate Members in General Meeting, shall be afterwards impeached by any member of the Institution on any ground whatsoever, but shall be deemed to be an act of the Institution.

NOTICES.

33. A notice may be served by the Council upon any Member, Associate Member, Graduate, Associate, or Honorary Life Member, either personally or by sending it through the post in a prepaid letter addressed to him at his registered place of abode.

34. Any notice, if served by post, shall be deemed to have been served at the time when the letter containing the same would be delivered in the ordinary course of the post; and in proving such service it shall be sufficient to prove that the letter containing the notice was properly addressed and put into the post office.

35. No Member, Associate Member, Graduate, Associate, or Honorary Life Member, not having a registered address within the United Kingdom, shall be entitled to any notice; and all proceedings may be had and taken without notice to such member, in the same manner as if he had had due notice.

By-laws.

(*Last Revision, February* 1894.)

MEMBERSHIP.

1. Candidates for admission as Members must be persons not under twenty-five years of age, who, having occupied during a sufficient period a responsible position in connection with the practice or science of Engineering, may be considered by the Council to be qualified for election.

2. Candidates for admission as Associate Members must be persons not under twenty-five years of age, who, being engaged in such work as is connected with the practice or science of Engineering, may be considered by the Council to be qualified for election, though not yet to occupy positions of sufficient responsibility, or otherwise not yet to be eligible, for admission as Members. They may afterwards be transferred at the discretion of the Council to the class of Members.

3. Candidates for admission as Graduates must be persons holding subordinate situations, and not under eighteen years of age. They must furnish evidence of training in the principles as well as in the practice of Engineering. Before attaining the age of twenty-six years, those elected after 1892 must apply for election as Members, Associate Members, or Associates, if they desire to remain connected with the Institution; they may not continue Graduates after attaining the age of twenty-six.

4. Candidates for admission as Associates must be persons not under twenty-five years of age, who from their scientific attainments or position in society may be considered eligible by the Council. They may afterwards be transferred at the discretion of the Council to the class of Associate Members or of Members.

5. The Council shall have the power to nominate as Honorary Life Members persons of eminent scientific acquirements, who in their opinion are eligible for that position.

6. The Members, Associate Members, Graduates, Associates, and Honorary Life Members shall have notice of and the privilege to attend all Meetings; but Members and Associate Members only shall be entitled to vote thereat.

7. The abbreviated distinctive Titles for indicating the connection with the Institution of Members, Associate Members, Graduates, Associates, or Honorary Life Members thereof, shall be the following:—for Members, M. I. Mech. E.; for Associate Members, A. M. I. Mech. E.; for Graduates, G. I. Mech. E.; for Associates, A. I. Mech. E.; for Honorary Life Members, Hon. M. I. Mech. E.

8. Subject to such regulations as the Council may from time to time prescribe, any Member, Associate Member, or Associate may upon application to the Secretary obtain a Certificate of his membership or other connection with the Institution. Every such certificate shall remain the property of, and shall on demand be returned to, the Institution.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. Each Member shall pay an Annual Subscription of £3, and on election an Entrance Fee of £2.

10. Each Associate Member shall pay an Annual Subscription of £2 10*s*., and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Members, he shall pay on transference 10*s*. additional subscription for the current year, and £1 additional entrance fee.

11. Each Graduate shall pay an Annual Subscription of £1 10*s*., but no Entrance Fee. Any Graduate elected prior to 1893, if transferred by the Council to the class of Associate Members, shall pay on transference £1 additional subscription for the current year, but no additional entrance fee; if transferred direct to the class of Members, he shall pay on transference £1 10*s*. additional subscription for the current year, and £1 additional entrance fee.

12. Each Associate shall pay an Annual Subscription of £2 10*s.*, and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Associate Members, he shall pay on transference no additional subscription or entrance fee. If transferred direct to the class of Members, he shall pay on transference 10*s.* additional subscription for the current year, and £1 additional entrance fee; except Associates elected prior to 1893, who shall pay no additional entrance fee on transference.

13. All subscriptions shall be payable in advance, and shall become due on the 1st day of January in each year; and the first subscription of Members, Associate Members, Graduates, and Associates, shall date from the 1st day of January in the year of their election.

14. In the case of Members, Associate Members, Graduates, or Associates, elected in the last three months of any year, the first subscription shall cover both the year of election and the succeeding year.

15. Any Member, Associate Member, or Associate, whose subscription is not in arrear, may at any time compound for his subscription for the current and all future years by the payment of Fifty Pounds, if paid in any one of the first five years of his membership. If paid subsequently, the sum of Fifty Pounds shall be reduced by One Pound per annum for every year of membership after five years. All compositions shall be deemed to be capital moneys of the Institution.

16. The Council may at their discretion reduce or remit the annual subscription, or the arrears of annual subscription, of any Member or Associate Member who shall have been a subscribing member of the Institution for twenty years, and shall have become unable to continue the annual subscription provided by these By-laws.

17. No Proceedings or Ballot Lists or Certificates shall be sent to Members, Associate Members, Graduates, or Associates, who are in

arrear with their subscriptions more than twelve months, and whose subscriptions have not been remitted by the Council as hereinbefore provided.

ELECTION OF MEMBERS, ASSOCIATE MEMBERS, GRADUATES, AND ASSOCIATES.

18. A recommendation for admission according to Form A or B in the Appendix shall be forwarded to the Secretary, and by him be laid before the next Meeting of the Council. The recommendation must be signed by not less than five Members or Associate Members if the application be for admission as a Member or Associate Member or Associate, and by three Members or Associate Members if it be for a Graduate.

19. All elections shall take place by ballot, four-fifths of the votes given being necessary for election.

20. All applications for admission shall be communicated by the Secretary to the Council for their approval previous to being inserted in the ballot list for election, and the approved ballot list shall be signed by the President and forwarded to the Members and Associate Members. The name of any Candidate approved by the Council for admission as an Associate Member or an Associate shall not be inserted in the ballot list until he has signed the Form C in the Appendix. The ballot list shall specify the name, occupation, and address of the Candidates, and also by whom proposed and seconded. The lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

21. The Elections shall take place at the General Meetings only.

22. When the proposed Candidate is elected, the Secretary shall give him notice thereof according to Form D; but his name shall not be added to the register of the Institution until he shall have paid his Entrance Fee and first Annual Subscription, and signed the Form E in the Appendix.

23. In case of non-election, no mention thereof shall be made in the Minutes, nor any notice given to the unsuccessful Candidate.

24. An Associate Member desirous of being transferred to the class of Members, or an Associate to the class of Associate Members or of Members, shall forward to the Secretary a recommendation according to Form F in the Appendix, signed by not less than five Members or Associate Members, which shall be laid before the next meeting of Council for their approval. On their approval being given, the Secretary shall notify the same to the Candidate according to Form G; but his name shall not be added to the list of Members or Associate Members until he shall have signed the Form H, and shall have paid the additional entrance fee (if any), and the additional subscription (if any) for the current year.

ELECTION OF PRESIDENT, VICE-PRESIDENTS, AND MEMBERS OF COUNCIL.

25. Candidates shall be put in nomination at the General Meeting preceding the Annual General Meeting, when the Council are to present a list of their retiring Members who offer themselves for re-election; any Member or Associate Member shall then be entitled to add to the list of Candidates. The ballot list of the proposed names shall be forwarded to the Members and Associate Members. The ballot lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

APPOINTMENT AND DUTIES OF OFFICERS.

26. The Treasurer shall be a Banker, and shall hold the uninvested funds of the Institution, except the moneys in the hands of the Secretary for current expenses. He shall be appointed by the Members and Associate Members at a General or Special Meeting, and shall hold office at the pleasure of the Council.

27. The Secretary of the Institution shall be appointed, as and when a vacancy occurs, by the Members and Associate Members at a General or Special Meeting, and shall be removable by the Council upon six months' notice from any day. The Secretary shall give the same notice. The Secretary shall devote the whole of his time to the work of the Institution, and shall not engage in any other business or profession.

28. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all meetings of the Institution, and of the Council, and of Committees; to take minutes of the proceedings of such meetings; to read the minutes of the preceding meetings, and all communications that he may be ordered to read; to superintend the publication of such papers as the Council may direct; to have the charge of the library; to direct the collection of the subscriptions, and the preparation of the account of expenditure of the funds; and to present all accounts to the Council for inspection and approval. He shall also engage (subject to the approval of the Council) and be responsible for all persons employed under him, and set them their portions of work and duties. He shall conduct the ordinary business of the Institution, in accordance with the Articles and By-laws and the directions of the President and Council; and shall refer to the President in any matters of difficulty or importance, requiring immediate decision.

MISCELLANEOUS.

29. All Papers shall be submitted to the Council for approval, and after their approval shall be read by the Secretary at the General Meetings, or by the Author with the consent of the Council; or, if so directed by the Council, shall be printed in the Proceedings without having been read at a General Meeting.

30. All books, drawings, communications, &c., shall be accessible to the members of the Institution at all reasonable times.

31. All communications to the Meetings shall be the property of the Institution, and be published only by the authority of the Council.

32. None of the property of the Institution—books, drawings, &c.—shall be taken out of the premises of the Institution without the consent of the Council.

33. All donations to the Institution shall be enumerated in the Annual Report of the Council presented to the Annual General Meeting.

34. The General Meetings shall be conducted as far as practicable in the following order:—

1st. The Chair to be taken at such hour as the Council may direct from time to time.

2nd. The Minutes of the previous Meeting to be read by the Secretary, and, after being approved as correct, to be signed by the Chairman.

3rd. The Ballot Lists, previously opened by the Council, to be presented to the Meeting, and the new Members, Associate Members, Graduates, and Associates elected to be announced.

4th. Papers approved by the Council to be read by the Secretary, or by the Author with the consent of the Council.

35. Each Member or Associate Member shall have the privilege of introducing one friend to any of the Meetings; but, during such portion of any meeting as may be devoted to any business connected with the management of the Institution, visitors shall be requested by the Chairman to withdraw, if any Member or Associate Member asks that this shall be done.

36. Every Member, Associate Member, Graduate, Associate, or Visitor, shall write his name and residence in a book to be kept for the purpose, on entering each Meeting.

37. The President shall ex officio be member of all Committees of Council.

38. Seven clear days' notice at least shall be given of every meeting of the Council. Such notice shall specify generally the business to be transacted by the meeting. No business involving the expenditure of the funds of the Institution (except by way of payment of current salaries and accounts) shall be transacted at any Council meeting unless specified in the notice convening the meeting.

39. The Council shall present the yearly accounts to the Annual General Meeting, after being audited by a professional accountant, who shall be appointed annually by the Members and Associate Members at a General or a Special Meeting, at a remuneration to be then fixed by the Members and Associate Members.

40. Any member wishing to have a copy of the Papers sent to him for consideration beforehand can do so by sending in his name once in each year to the Secretary; and a copy of all Papers shall then be forwarded to him as early as possible prior to the date of the Meeting at which they are intended to be read.

41. At any Meeting of the Institution any member shall be at liberty to re-open the discussion upon any Paper which has been read or discussed at the preceding Meeting; provided that he signifies his intention to the Secretary at least one month previously to the Meeting, and that the Council decide to include it in the notice of the Meeting as part of the business to be transacted.

APPENDIX.

FORM A.

Mr.   being   years of age, and desirous of admission into The Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our personal knowledge, and the three other signers from trustworthy information, propose and recommend him as a proper person to belong to the Institution.

Witness our hands, this   day of

Members or Associate Members.

FORM B.

Mr.   born on   being desirous of admission into The Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our personal knowledge, and the other signer or signers from trustworthy information, propose and recommend him as a proper person to become a Graduate thereof.

Witness our hands, this   day of

Members or Associate Members.

FORM C.

If elected an   of The Institution of Mechanical Engineers, I, the undersigned, do hereby engage to ratify my election by signing the form of agreement (E) and paying the Entrance Fee and Annual Subscription in conformity with the By-laws.

Witness my hand, this   day of

FORM D.

Sir,—I have to inform you that on the   you were elected a   of The Institution of Mechanical Engineers. For the ratification of your election in conformity with the rules, it is requisite that the enclosed form be returned to me with your signature, and that your Entrance Fee and first Annual Subscription be paid, the amounts of which are   and   respectively. If these be not received within two months from the present date, the election will become void.

I am, Sir, Your obedient servant,

Secretary.

FORM E.

I, the undersigned, being elected a of The Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they are now formed or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

FORM F.

Mr. being years of age, and desirous of being transferred into the class of of The Institution of Mechanical Engineers, we, the undersigned, from our personal knowledge recommend him as a proper person to be so transferred by the Council.

Witness our hands, this day of

Members or Associate Members.

FORM G.

Sir,—I have to inform you that the Council have approved of your being transferred to the class of of The Institution of Mechanical Engineers. For the ratification of your transference in conformity with the rules, it is requisite that the enclosed form be returned to me with your signature, and that your additional Entrance Fee and additional Annual Subscription for the current year be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the transference will become void.

I am, Sir, Your obedient servant,

Secretary.

FORM H.

I, the undersigned, having been transferred to the class of of The Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they now exist, or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

The Institution of Mechanical Engineers.

PROCEEDINGS.

JANUARY 1906.

An ORDINARY GENERAL MEETING was held at the Institution on Friday, 19th January 1906, at Eight o'clock p.m.; EDWARD P MARTIN, Esq., President, in the chair.

The Minutes of the previous Meeting were read and confirmed.

The PRESIDENT announced that, in accordance with the Rules of the Institution, the President, two Vice-Presidents, and seven Members of Council, would retire at the ensuing Annual General Meeting; and the list of those retiring was as follows:—

PRESIDENT.

EDWARD P. MARTIN,	Abergavenny.

VICE-PRESIDENTS.

JOHN A. F. ASPINALL,	Manchester.
A. TANNETT-WALKER,	Leeds.

MEMBERS OF COUNCIL.

H. F. DONALDSON,	Woolwich.
J. ROSSITER HOYLE,	Sheffield.
HENRY LEA,	Birmingham.
MICHAEL LONGRIDGE,	Manchester.
JOHN F. ROBINSON,	London.
JAMES ROWAN,	Glasgow.
JOHN W. SPENCER,	Newcastle-on-Tyne.

All of the foregoing had offered themselves for re-election, and had been nominated by the Council.

The following Nominations had also been made by the Council for the election at the Annual General Meeting:—

Election as Members.	MEMBERS OF COUNCIL.	
1885.	WILLIAM H. ALLEN, ...	Bedford.
1882.	THOMAS P. REAY, ...	Leeds.

The above gentlemen had both consented to the Nomination.

The PRESIDENT reminded the Meeting that, according to the Rules of the Institution, any Member or Associate Member was then entitled to add to the list of candidates.

No other names being added, the PRESIDENT announced that the foregoing names would accordingly constitute the nomination list for the Election of Officers at the Annual General Meeting.

The PRESIDENT announced that the Ballot Lists for the election of New Members had been opened by a Committee of the Council, and that the following fifty-one candidates were found to be duly elected:—

MEMBERS.

BLAND, JOHN PARKINSON, . . .	London.
BREARLEY, WILLIAM HENRY, . .	Sheffield.
CLARK, WILLIAM FREDERICK, . .	Birmingham.
CUMING, GEORGE, ...	Belfast.
HUME, EDWARD SHOTTON, . . .	Perth, W. Australia.
MELLANBY, ALEXANDER LAWSON, . .	Glasgow.
MENZIES, JOHN, ...	Glasgow.
OWEN, THOMAS, ...	Liverpool.
PARKER, JOSEPH EDMUNDSON, . .	Bulawayo.
SMITH, JOHN, ...	Liverpool.

STOWE, GEORGE SULLY,	Johannesburg.
SUDWORTH, SAMUEL,	London.
TWENTYMAN, HAROLD EDWARD,	Wolverhampton.
WORSDELL, HENRY,	London.

ASSOCIATE MEMBERS.

BENFIELD, JOHN,	Sheffield.
BENT, WILLIAM,	Wolverhampton.
COOK, JOHN,	Northwich.
COOPER, ARTHUR COATH,	Rochdale.
CROOKER, ERNEST GEORGE,	Rosyth, Fife.
FAWNS, SYDNEY,	London.
HART, WILLIAM HENRY,	Malta.
HASLAM, SIDNEY BERTRAM,	Cardiff.
HUNTER, CHARLES FREDERICK,	Sunderland.
KERR, ROBERT FYFE,	Manchester.
KINGHORN, DAVID MORGAN,	London.
MACKINDER, JOHN HERBERT,	Reddish, Stockport.
MACKLIN, EDWARD LIONEL,	London.
MILES, ERNEST GEORGE,	Derby.
OMANT, PERCY LUTHER,	Croydon.
PETTIT, CHARLES WILLIAM,	Hanworth, Middlesex.
PETTIT, WALTER RICHARD,	Chester.
PITCAIRN, FRANCIS BERNARD,	Shanghai.
POWELL, LLEWELLYN HENRY,	Rose Belle, Mauritius.
PRATT, HARRY KEAY,	Hednesford.
RUSHWORTH, DAVID,	Chesterfield.
SELLER, EDWARD,	Erith.
SHARPE, GERALD,	Erith.
SILBY, ROBERT PASSMORE,	Singapore.
STOREY, CLIFFORD BARTON,	Cape Town.
THOMAS, JAMES LLOYD,	London.
TIMMINS, EBENEZER,	Runcorn.
WESTON, ROBERT OGILVY,	Sebakwe, S. Rhodesia.
YOUATT, CLAUDE SEPTIMUS,	Manchester.

GRADUATES.

Butler, Stanley Gordon, . . .	London.
Flanagan, John Henry Woulfe, . .	London.
Green, Ernest William, . . .	Newport, Mon.
Lloyd, William Stanley, . . .	London.
Longbottom, John Leonard, . . .	Wakefield.
Meadows, Albert, ...	London.
Minshull, John Williams, . . .	Kilkenny.
Wheaton, Harold Joseph, . . .	London.

The President announced that the following three Transferences had been made by the Council :—

Associate Members to Members.

Abel, Walter Robert, ...	Leeds.
Bulfin, Ignatius, ...	Bournemouth.
Clemence, Walter, ...	London.

The Discussion on Mr. E. G. Izod's Paper on "Behaviour of Materials of Construction under Pure Shear" was resumed and concluded.

The following Paper was then read and discussed :—

"Worm Contact"; by Mr. Robert A. Bruce, *Member*, of Leeds.

The Meeting terminated shortly before Ten o'clock. The attendance was 116 Members and 43 Visitors.

BEHAVIOUR OF MATERIALS OF CONSTRUCTION UNDER PURE SHEAR.

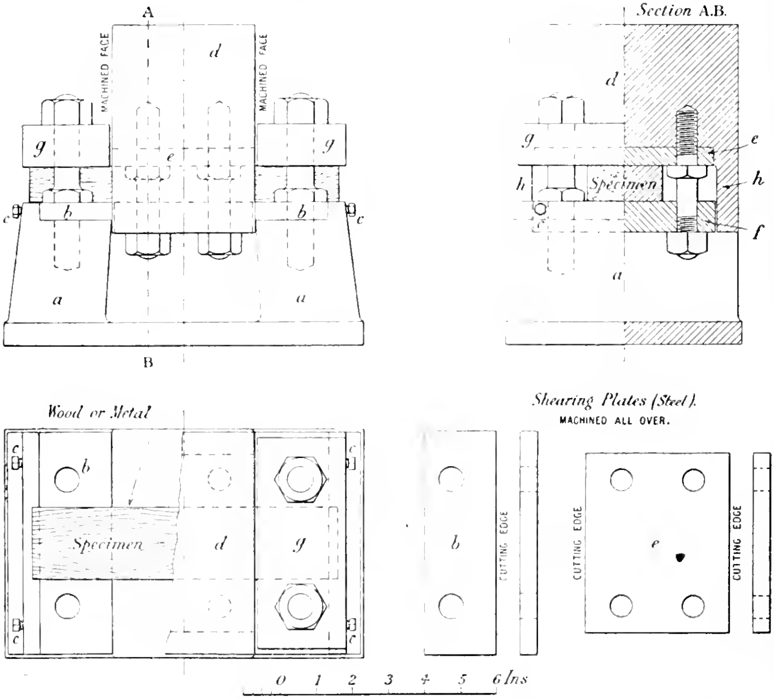
By Mr. E. G. IZOD, *Associate Member*, of Rugby.

The title of this Paper being perhaps rather far reaching, it may not be out of place to explain that in the following series of experiments only the better known and more commercially used materials were tested, though it is hoped that the results obtained may be somewhat of a guide in forecasting results from other materials that do not come within the scope of these experiments. Time was such an important factor in carrying out these tests that the author could not make them as complete as could be wished, but he hopes that some of the results now set forward may be found useful and interesting.

The experiments were carried out at University College Engineering Laboratory, and were undertaken in the first case to investigate the effect of shear on cast-iron, concerning which there seemed rather a lack of data; these experiments proving useful, they were extended to embrace a somewhat wider field as shown in the results attached. The main stumbling block in experiments on shear seems to be that bending, or stretching of the outer fibres in the specimens tested, cannot be entirely eliminated, and to remedy this as far as possible a particular form of shearing apparatus has been used.

The apparatus is shown in Fig. 1. *a* is a stiff cast-iron body composed of two projecting supports, which are cast in one with the bedplate. These supports carry hardened steel plates *bb* with edges ground for cutting edges; these side plates are screwed to the supports by the holding-down bolts which grip the specimen, the edges being spaced exactly 4 inches apart, which is the general

FIG. 1.—*Gear for Shear Experiments.*
(See Figs. 8 and 9, Plate 1.)



span adopted for the experiments. The plates are capable of fine adjustment by the means of the small set-screws *cccc*. Between these side plates another cast-iron block, *d*, slides, which also holds a steel plate *e* with cutting edges; this middle plate exactly fits between the two side plates so that the opposite edges shall induce as near perfect shear as possible. The specimen is then screwed down

to the middle plate by means of the cap and holding-down bolts, Fig. 8, Plate 1, and the projecting ends placed on the two side plates and held firmly by the caps g and side bolts; the whole apparatus is then placed between the compression plates of the testing machine, and the tests carried out in the usual manner. The projecting lugs h serve as guides to ensure the middle block d moving fairly between the side plates. The apparatus is shown in the testing machine, Fig. 9, Plate 1. The testing machine used was a 100,000 lbs. Greenwood and Batley horizontal machine, and all the jockey weights were carefully calibrated. The specimens used were as nearly alike as could possibly be obtained, but a great deal depended on the form in which the material was supplied, this varying with different makers; in all cases a rectangular section was used for the shearing tests, while for the tensile tests a general rule was followed where possible for the flat and round specimens.

Several experiments were made in the early stages to determine the effect of form or shape of section on the Ultimate Shear Stress, which perhaps deserves a passing mention. A mild-steel bar was taken and specimens cut from it consecutively, and treated in a different manner as regards the shearing area, such as—

(1) Nicked with various widths of cutting tool.
(2) Fine saw cuts to various depths.
(3) Turned grooves with various radii at the bottom.
(4) Recesses machined for the knife-edges, etc.

These gave results practically identical with those from the plain bar, so that the rectangular sections as tested could be relied upon to give satisfactory results and an accurate measure of the ultimate shear strength for all materials.

A summary of all the results obtained is shown in Table 1 (page 9), and plotted against Materials Base in Fig. 2 (page 8). Each figure in the Table is the mean of a large number of separate tests; where the elongation percentage is given, it is the corrected elongation percentage for a standard bar 2 inches long and $\frac{9}{16}$ inch diameter, having therefore a ratio of $\frac{l}{d} = 3 \cdot 54$.

Ultimate Tensile Stress is designated by F_t.

Ultimate Shear Stress is designated by F_s.

FIG. 2.—*Results plotted on "Materials" Base.* (See Table 1.)

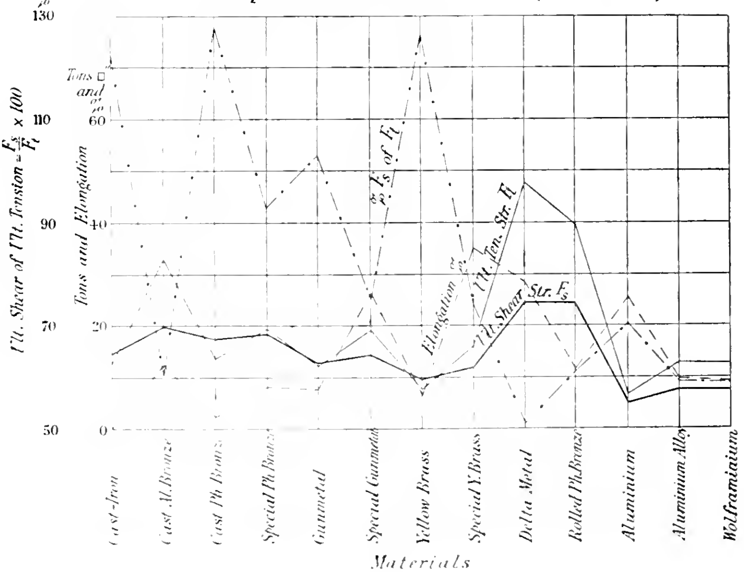


FIG. 3.—*Results on Steel. Plotted against "Material" representing various qualities of Steel.* (See Table 1.)

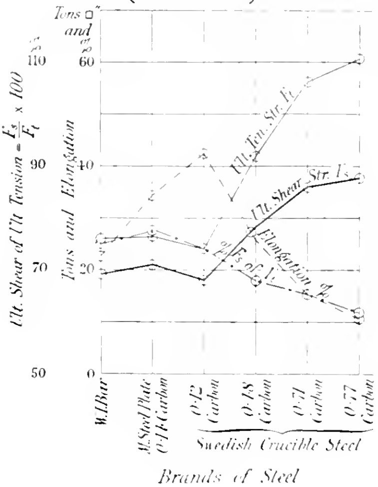


FIG. 4.—*Results on Swedish Crucible Steel with varying Percentages of Carbon.*

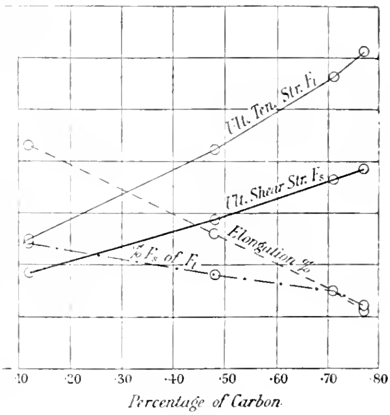


TABLE 1.

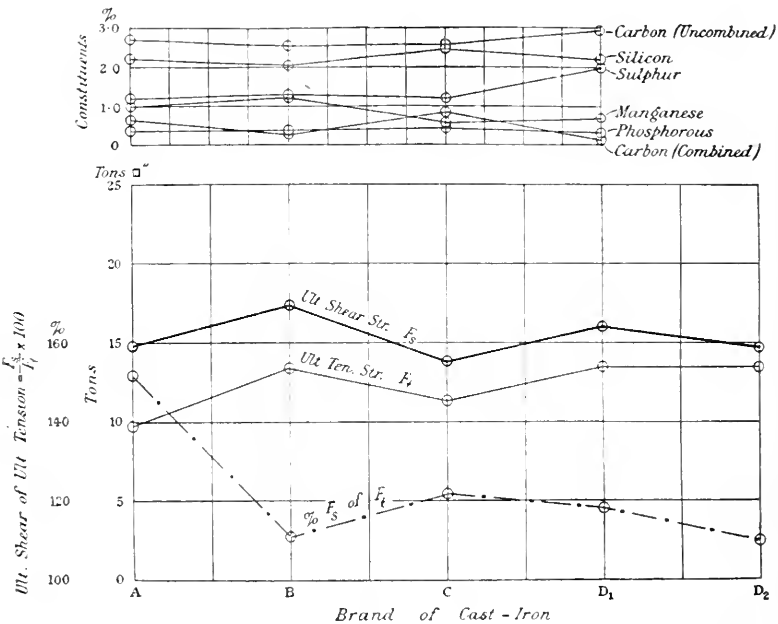
Summary Table of Results.

Results plotted on "Materials" Base, Figs. 2, 3 and 5 (pages 8 and 10).

Material.	Ultimate Tensile Stress. Tons per sq. in. $= F_t$.	Elongation Percentage on Standard.	Stretch Modulus E. Tons per sq. in.	Ultimate Shear Stress. Tons per sq. in. $= F_s$.	Per cent. of Ultimate Shear of Ultimate Tensile Stress $= \frac{F_s}{F_t} \times 100$.
Cast-Iron. A	9·7	—	6000	14·8	152·0
,, ,, B	13·4	—	8300	17·4	111·0
,, ,, C	11·3	—	5700	13·9	122·0
,, ,, D_1	13·7	—	6200	16·1	118·0
,, ,, D_2	13·5	—	5900	14·8	110·0
Cast Aluminium-Bronze	33·1	12 5	7600	19·9	60·0
,, Phosphor-Bronze	13·4	2·2	—	17·2	128·0
Special Cast Phosphor-Bronze	19·7	8·0	—	18·4	93 0
Gunmetal	12·1	7·8	—	12·5	103·0
Special Gunmetal	19·0	26·5	—	14·3	75·0
Yellow Brass	7·5	6·5	—	9·4	126·0
Special Yellow Brass	16·0	35·0	—	11·8	74·0
Delta Metal	47·3	28·3	—	24·2	51·0
Rolled Phosphor-Bronze	39·5	11·7	—	24·2	61·0
Aluminium	6·4	25·5	—	4·5	70·0
Aluminium Alloy	12·7	9·6	—	7·5	59·0
Wolframinium	12·6	9·2	—	7·5	59·0
Wrought-iron Bar	26·0	22·5	—	19 4	75·0
Mild-Steel Plate 0·14 Carbon	26·9	34·7	—	21·0	78·0
Swedish Crucible Steel :—					
0·12 Carbon	24·9	43·0	—	18·5	74·0
0·48 ,,	42·1	26·0	—	28·8	68·0
0·71 ,,	56·3	15·0	—	36·6	65 0
0·77 ,,	61·3	11·0	—	38·3	62·0

Cast-Iron.—Four brands were tested, and the mean results give a higher Ultimate Shear Stress for cast-iron than is generally accepted; the average for all brands being 14·9 tons per square inch, while in several cases it exceeded 16·0 tons. An attempt was made to establish a rule as a guide to the ratio $\frac{F_s}{F_t}$, but this ratio did not seem to be dependent on any of the other results observed. Though

FIG. 5.—*Shear and Tensile Tests of Cast-iron with Analyses of Different Brands.*
(Iron represented by difference.)
(See Table 1.)



the variation with different brands is not great, yet it cannot be said to follow any law which can be deduced from these experiments. Analysis is plotted against these results in Fig. 5. The fractured specimens showed that, even though the material was well supported round the knife-edges by the holding-down caps, yet a local stretching took place in the outer skin, in this case of course showing as a slight crack across the specimen about $\frac{1}{8}$ inch from the

shearing plane. It was observed also that the fracture line took the form of an S bend with the bulge towards the knife-edge as shown in Fig. 10, Plate 1.

Cast Aluminium-Bronze.—These specimens have a high Ultimate Tensile Stress with rather low Ultimate Shear Stress, the ratio $\frac{F_s}{F_t}$ being only 60 per cent. The shear fracture, Fig. 13, Plate 2, did not show much sign of the knife-edges having had a cutting action on the material, it having apparently stood the load up to the maximum without much deformation, and then entirely fractured at this load. In the Tensile Tests it was noted that the reduction of area before and at fracture was not local, but extended over the whole length of the bar, breaking it up into corrugated ridges almost as though the material was rolled and fibrous.

Cast Phosphor-Bronze.—The ordinary material gave a high ratio $\frac{F_s}{F_t}$, and the same material was specially treated in casting, with the result that the whole of the figures were improved, the ratio $\frac{F_s}{F_t}$, however, decreasing from 128 to 93 per cent. A very curious fracture was observed with the special material, which is a very aggravated form of the fracture noticed in mild-steel, etc. When the specimen was sheared, it was found that the fracture line had taken two distinct paths in such a manner that there was a plug of the material left in the shear plane, untouched by the knife-edges. This fracture appeared in all the shear tests of the special phosphor-bronze, and is shown very clearly in Fig. 17, Plate 2, where there is also shown a shear fracture of ordinary cast phosphor-bronze. This is possibly due to the very homogeneous nature of the special material, as the fracture line has apparently started in a similar manner to that explained in the mild-steel tests (page 13), but has simultaneously extended to the opposite knife-edge in such a manner that there is left the knot or plug of material mentioned above.

Gunmetal.—In this case, similarly to that of phosphor-bronze, the special treatment has considerably improved the test figures, though the ratio $\frac{F_s}{F_t}$ has dropped from 103·0 to 75 per cent.

Yellow Brass.—The improvement due to special treatment is here even more marked than in the two previous cases, though the variation in results is what might be expected from the former tests.

Delta Metal.—This gave the highest Ultimate Tensile Stress of all the materials, the Ultimate Shear Stress being equal to that of rolled phosphor-bronze, while the ratio $\frac{F_s}{F_t}$ was 51·0 per cent. The shear fracture was fine and clean, but presented a curious feature in that the material showed no trace of cutting of the knife-edges except at the extreme outside of the specimen, where the metal had apparently bunched up into a knot, and was either entirely cut by the descending knife-edges or else torn clean away, leaving two projections in one portion of the sheared specimen with corresponding recesses in the other. This peculiarity is shown very clearly in Fig. 15, Plate 2.

Rolled Phosphor-Bronze.—This proved very tough material, with high Ultimate Tensile Stress 39·5 tons per square inch and a fairly low elongation. The Ultimate Shear Stress was 24·2, and there is a rather low ratio $\frac{F_s}{F_t}$ of 61·0 per cent. Shear fracture was very smooth and clean, and showed traces of the knife-edges, with very little stretching of the outer fibres.

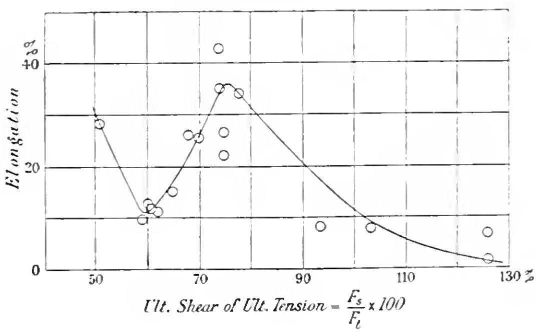
Aluminium.—This gave fairly high elongation with ratio $\frac{F_s}{F_t}$ of 70·0. Shear fracture was smooth and clean, showing the cutting action of the knife-edges very plainly.

Aluminium Alloy.—Ultimate Tensile Stress in this case was nearly double that of aluminium, while the ratio $\frac{F_s}{F_t}$ was only 59 per cent. or 11 per cent. less. Shear fracture showed the peculiar ridge described later in Mild-Steel Tests, Fig. 14, Plate 2.

Wolframinium.—This gave results almost coinciding with the former aluminium alloy, the only difference being, if anything, slightly lower elongation percentage. The shear fracture was similar to No. 4 Alloy and Mild-Steel.

Mild-Steel and Wrought-Iron.—It was intended to make these tests on a large number of steels with varying percentages of carbon, including the higher carbon steels; but unfortunately steel makers, who would have supplied a series of test pieces with their proportionate analyses, were not able to furnish them at the last minute, consequently the experiments are not so complete as they might be. The author was enabled to include however a series of

FIG. 6.—*Curve showing possible variation of Elongation per cent., with ratio* $\frac{F_s}{F_t}$.



tests on some Swedish crucible steel, with varying percentages of carbon, and these results are plotted in Fig. 4 (page 8). Contrary to expectation, the ratio $\frac{F_s}{F_t}$ decreased as the carbon content increased; but the author is inclined to think that this confirms the deductions arrived at from the curve in Fig. 6 and explained later, namely, that as the ratio $\frac{F_s}{F_t}$ falls from 80 to 60 per cent. the elongation percentage also decreases, whereas, if the elongation dropped considerably lower than 10 per cent., as might be expected with higher carbon steels, the ratio $\frac{F_s}{F_t}$ would be proportionately higher.

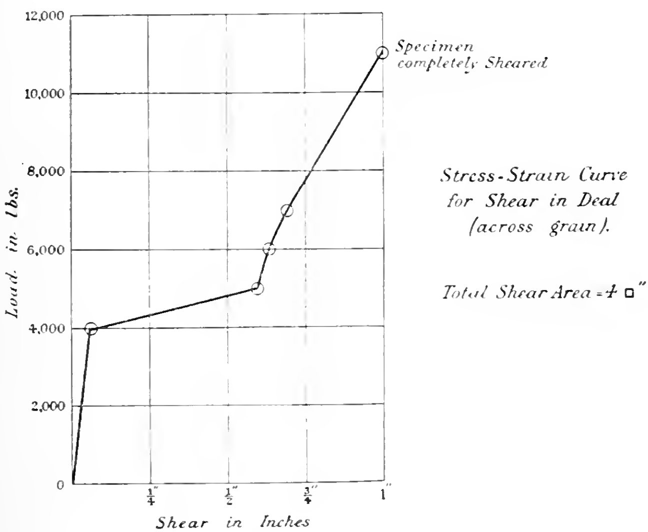
A very curious feature of the tests on Mild-Steel was the peculiar form of fracture, there being left a very decided knife-edge standing away from the rest of the material, as shown in Fig. 11, Plate 1, and in the specimen exhibited. This peculiarity was noted in two other materials tested; and to investigate it, a specimen of mild steel was specially prepared with horizontal and vertical lines drawn $\frac{1}{32}$-inch apart, each side of the shearing plane; this was then placed in the machine and the load taken off when the specimen was half sheared. The effect of the shearing action is shown in Fig. 12, Plate 1, which are from each end of the half-sheared specimen exhibited. It can be seen that the fracture starts along a line inclined at an angle to the vertical shearing plane, but in an opposite direction to that of cast-iron, which was *towards* and *under* each respective knife-edge, while in this case of mild steel the direction is to the other side of the vertical plane, and away from the knife-edge. The cause of the projecting ledge mentioned above is most probably explained as follows:—When the knife-edges move towards one another under the gradually applied load, the fracture line starts obliquely from each, and as they come together the fibres of the intervening material are compressed and twisted through nearly a right angle until finally fracture takes place along the fibres. The knife-edges separate this isolated portion through the vertical plane in which they are forced to move, thus making the ridge mentioned, the front of which is due to the cutting action of the knife-edge, while the back is due to the primary fracture line at the commencement of the load. This experiment also showed that it was practically impossible to prevent a certain amount of stretching of the top fibres in shearing tests, as, though the material was well supported by the holding-down caps, these fibres were effected for $\frac{1}{2}$-inch each side of the shearing plane, as shown by the inclination of the top portion of the vertical lines; this stretching or bending is due to the fact that, when the load comes on the specimen, a certain amount of compression takes place before any fracture occurs, which brings the material away from the holding-down caps, and so leaves it to a certain extent unsupported and free to stretch.

Woods.—Four kinds of woods were used for these tests.

(1) Pollard Oak.
(2) Yellow Deal.
(3) Yellow Pine.
(4) Teak.

From a selected board of each, specimens for Tension and Shear were cut alternately, in order to ensure any possible variation in the quality of the board being well distributed. The Shear specimens were cut 8 inches by 2 inches by 1 inch, and tested along and across the grain. The results are given in Table 2 (page 16).

FIG. 7.



On testing the woods in Shear across the grain, it was observed that the specimen remained steady up to a certain load, and then sheared through about three-fourths of its shearing area, when it required a further increase of load, sometimes as much as twice the amount to shear the specimen completely; the author has named this the "crippling load," and it is shown more clearly in a Shear Stress-Strain diagram, Fig. 7, which was drawn for a specimen of Deal sheared across the grain. The exception to this is the case of Oak,

TABLE 2.

Tests of Wood in Shear and Tension.

Kind of Wood.	Weight of Cubic Foot.	Ultimate Tensile Stress.		Across Grain Crippling Load.	Ultimate Shear Stress.		Percentage Crippling Load across Grain of Ultimate Tensile Stress.	Percentage Ultimate Shear Stress across Grain of Ultimate Tensile Stress.	Percentage Ultimate Shear Stress along Grain of Ultimate Tensile Stress.	Percentage of Moisture.
					Across Grain.	Along Grain.				
	Lbs.	Lbs. per sq. in.	Tons per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.				
Pine	39·5	9,176	4·09	1,930	4,872	470	21·0	53·0	5·12	15·7
Oak	47·7	15,993	7·14	(Apparently none)	5,292	891	—	33·0	5·5	12·6
Deal	26·46	7,834	3·49	1,195	2,668	442	15·2	34·0	5·6	10·6
Teak	45·0	9,807	4·37	2,764	3,960	1,022	28·2	40·4	10·4	10·0

where no "crippling load" is really apparent, and which sheared through at its maximum load directly the centre knife-edge commenced to move. In Teak specimens sheared *across* the grain, the fibres did not hold together as in the other woods, but broke away from the main specimen at about $\frac{3}{4}$ inch from the shearing plane. This is shown in Fig. 16, Plate 2.

The percentage of moisture in each wood was obtained by carefully weighing the broken specimens, then placing them in a temperature of 212° F. for 80 hours and weighing again immediately on removal. Towards the conclusion of the experiments it occurred to the author that the apparently pure double-shear, induced by the apparatus used, might not be simultaneous over the whole area, and to investigate the matter an arrangement was adopted as follows:—To the centre block carrying the middle knife-edge a stiff steel beam was screwed, each end of which carried a steel pointer; to the crosspiece of the testing machine which carried the compression plate two brackets were fixed which carried smoked iron plates, the steel pointers on the beams resting lightly on each, and were adjusted with springs to move without friction on the plates. The multiplying effect each side of the centre block was, by means of the long steel beam, 16 to 1, that is, a movement of $\frac{1}{8}$ inch on the pointer would mean a corresponding movement of the knife-edge of $\frac{1}{128}$ inch. A specimen was placed in the shearing shackles, and the whole just gripped between the compression plates sufficiently to prevent slipping; the steel beam was then screwed down to the centre block, and the pointers adjusted to rest just lightly on the smoked plates. A zero line was then drawn on each plate at the place where the pointers rested; small increments of load were then put on, and each pointer carefully watched and the positions marked for the corresponding loads. It can be seen that should there be any tendency of the knife-edges *not* to move absolutely in synchronism due to even a *small* failure of one side of the specimen before the other, the beam would immediately set itself at some small angle, and consequently the pointers would record the movement and locate it. This arrangement would also give a fairly accurate stress-strain diagram for any material tested, and some observations

were taken on a specimen of Yellow Deal, from which the Stress-Strain curve, Fig. 7 (page 15), was plotted. A specimen of mild steel bar tested with this gear on showed that the material remained perfectly steady up to half its maximum load, after which it began to shear, the movement of the knife-edges being regular for successive increments of load until fracture took place. In all the experiments this arrangement showed that there was no tendency for one side to fail before the other, the shear being apparently simultaneous over the whole area.

All the results obtained in these experiments seem to point to the fact that there is no common law connecting the Ultimate Shearing Stress with the Ultimate Tensile Stress, the ratio $\frac{F_s}{F_t}$ varying greatly with different materials. The test figures from the crystalline materials, such as cast-iron or those with very little or no elongation, seem to indicate that the Ultimate Shear Stress *exceeds* the Ultimate Tensile Stress by as much as 20 or 25 per cent., while from the fibrous materials, or, more properly speaking, those with a fairly high measure of ductility, the Ultimate Shear Stress may be anything from 0 to 50 per cent. less than the Ultimate Tensile Stress.

A curve was drawn, Fig. 6 (page 13), showing the variation of elongation percentage with the ratio $\frac{F_s}{F_t}$, and from this it can be seen that there is a certain amount of uniformity in the results. When the ratio $\frac{F_s}{F_t}$ is close to the 60 per cent., the elongation in every case shows very little variation from 10 per cent. Below, and above the 60 per cent. ratio the elongation increases, that at 50 per cent. ratio being almost equal to that at 70 per cent., while from the 70 per cent. ratio upwards the variation is inclined to be regular, the elongation decreasing as the ratio $\frac{F_s}{F_t}$ becomes higher, until with a very small or practically no elongation the ratio might be expected to reach 120 per cent. or 130 per cent., that is, that the Ultimate Shear Stress would exceed the Ultimate Tensile Stress by 20 or 30 per cent. Further experiments might throw more light on this subject, and the author regrets that he was unable to extend the series of tests

to embrace a wider and consequently more interesting field. All the results obtained are shown plotted to a Materials Base in Figs. 2, 3, and 5 (pages 8 and 10). Curves, sketches of apparatus used, and also a series of photographs of fractures of test pieces, etc., are appended. They are tabulated under the different headings in order to give a better reference for any details; and to those who are interested in the subject of strength of materials they, together with the samples shown, will do more to shed a small light on the subject than any remarks by the author. In conclusion, the author wishes to thank Professor T. Hudson Beare for the great interest he has at all times taken in the experiments, and also the undermentioned firms for the extreme courtesy and kindness which they have shown in supplying material for the experiments, and in providing information and data for use with the tests:—The British Aluminium Co., The Delta Metal Co., The Phosphor-Bronze Co., The Leeds Forge Co., and Messrs. Willans and Robinson. The author wishes also to express his thanks to Mr. E. M. Eden of University College, who kindly carried out a second series of Sheai Tests on the specially treated Alloys.

The Paper is illustrated by Plates 1 and 2 and 7 Figs. in the letterpress.

Discussion on Friday, 15th December 1905.

Professor W. E. LILLY thought that the title of the Paper, "The Behaviour of Materials of Construction under Pure Shear," was a mistake. A pure-shear stress could only be applied by means of the torsion test. He knew no other means of applying what was called pure-shear test in a practical way, and therefore when the author stated "The Behaviour of Materials of Construction under Pure Shear" he was hardly correct, in that the term "Pure Shear" should not have been used. All that were being dealt with

(Professor W. E. Lilly.)

were shearing stresses, such as were obtained by means of single or double shear-tests or tests of a similar kind.

The next point he wished to raise occurred in connection with the statement on page 7: "The rectangular sections as tested could be relied upon to give satisfactory results and an accurate measure of the ultimate shear strength for all materials." The author then deduced a curve, showing the ratio of the shearing stress, F_s, to the tensile stress F_t, and assumed that the shear tests gave an accurate measure of the ultimate shear strength in comparison with the tensile test which he had obtained. If an ordinary bar were taken and tested, in single or double shear, a certain value was obtained for the shear stress. If the thickness of the bar were doubled and a test again made, the same value for the shear stress would not be obtained the second time. Mr. J. Hartley Wicksteed published in "The Engineer" * some tests, made with a 300-ton testing machine, upon steel bars 3 inches wide and ranging from $\frac{1}{2}$ inch up to $2\frac{1}{2}$ inches thick, and the values he obtained for the shearing stress varied from 19·5 tons per square inch when the bar was $\frac{1}{2}$ inch thick to 17·3 tons per square inch when the bar was $2\frac{1}{2}$ inches thick. It would thus be seen that, under exactly the same conditions of testing, Mr. Wicksteed obtained two different figures for the value F_s; in other words, the single or double shear-test was a destructive test, of a kind in which the load was not uniformly applied all over the section, the consequence being that if different depths were taken different results would be obtained. Mr. Wicksteed also showed that the depth of penetration varied. The depth of penetration was $\frac{1}{10}$ inch when the bar was $\frac{1}{2}$ inch thick, and it varied up to 0·55 inch when the bar was $2\frac{1}{2}$ inches thick. That showed that the value of F_s was not constant and independent of the depth of the bar, as assumed by the author. From the Paper it was only possible to get the value of the ratio of F_s to F_t for the particular thickness of bar Mr. Izod had tested, about 1 inch thick and 2 inches wide.

* "The Engineer," 2 September 1904, page 236.

He thought it would have been very much better, and would have added much more to the value of the Paper, if Mr. Izod had made some experiments upon the compressive strength at the same time. When materials were being tested, it was of the utmost importance to know the relation between the compression strength, the pure shear strength, and the tensile strength. The pure shear strength was the one that was usually obtained from the torsion test, and it was obviously true that for most materials there must be a direct relation between the strength to compression, shear and tension. A great many experiments were made in which the observer only noticed the shear strength and the tensile strength. It would have been a great deal better if the third test had been added, because if that had been done, future workers in the field would find that if there was any relation between the strengths they would have sufficient data to go upon. He was of the opinion that, for all isotropic materials, the order of strengths was as follows: the compression strength stood first as always the greatest, the pure shear strength followed next, and the tensile strength was third. From the results in the Paper that statement would be questioned at once, but from the experiments he had made upon the annealed materials under those three tests he found that, as a rule, the three strengths lay in the order he had named, and it was only under exceptional conditions that a pure shear strength less than the tensile strength was obtained. Of course he knew from the experimental work done by others that the statement would be strongly criticized; if however the condition of the materials at the time of testing were examined, he was of opinion that the results that had been obtained would not be found to hold conclusively.

Professor C. A. CARUS-WILSON was sorry so short a time remained for discussing the Paper, because he thought the subject was a far more important one than the deductions of the author appeared to make it. The author had come to the conclusion that the problem he had undertaken to investigate was practically insoluble. It was not insoluble, and the author's own statistics in the Paper, if one had time to go into them, would afford a complete answer to the problem

(Professor C. A. Carus-Wilson.)

he had put forward. The question of the relation of the tensile strength to the shearing strength was a perfectly comprehensible one, easy to understand and easy to demonstrate by experiment. The author had made a mistake in his tests to begin with, in adopting an entirely arbitrary method of estimating the tensile stress by taking the maximum load on the original area. But when the relation of shearing stress to tensile stress was being investigated, he thought it stood to reason that one could not expect to get any results if they began by taking an arbitrary measure of the tensile stress. If the author had taken the actual tensile stress at rupture, the measured load at rupture on the reduced area, and estimated from that the true shearing stress at the moment of rupture, and had compared it with the shearing strength obtained on the same material by a shearing experiment, he would have found an absolute identity. About fifteen years ago he had made some experiments on the subject at the engineering laboratory at Coopers Hill, which were published in the Proceedings of the Royal Society,* and over a very large range of tests he ascertained that the true tensile stress at rupture and the shearing stress as obtained by the shearing experiments, came out nowhere more than 5 per cent. different, and with a mean percentage of difference of only 3 per cent. Sir George Darwin had pointed out some time ago that when a bar was subjected to a longitudinal stress two effects were produced; the material dilated uniformly, and a distortion was produced in each element of the material dealt with. Sir George went on to show that it was not conceivable that a bar could be broken by dilating it to any extent; he therefore concluded that the only possible way in which material could break was by the overcoming of a certain resistance to shear. The experiments above alluded to were made with the object of proving the truth of that conclusion, and they proved it. When a bar broke, the breaking took place because such a tensile strength was applied as produced incidentally a shearing stress, which, when it reached the maximum resistance to shearing, was immediately succeeded by rupture.

* Proceedings, Royal Society, vol. xlix. 1890, page 243.

The question of what it was that actually produced rupture in a bar was one of extreme importance. He thought if the author would take his own data and actual loads, compute them upon the reduced area and compare them with the maximum shearing stresses, he would in every case get an equality. It might at first sight be difficult to see how it came about that a bar broke by shearing and not by tension. When one saw a load put on a bar, and fracture taking place over a cross-section, it was said that of course there was

FIG. 18.

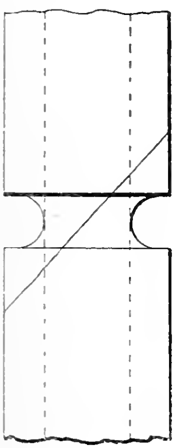
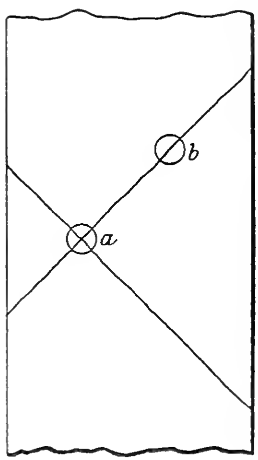


FIG. 19.



a certain amount of tension produced; the two sections separated, and that was the end of it. But it was necessary to consider what happened in the process of breaking. There was a certain resistance overcome. That resistance could only be a resistance to shearing, and it followed that the resistance to shearing was the true ultimate criterion of the strength of any material. There was produced over the cross-section of every test-bar a certain tension, and at the same time a tendency to slide. The maximum stress tending to slide was half of the tension, and was experienced over the whole of the cross-sectional area. What happened at rupture was that on any small

(Professor C. A. Carus-Wilson.)
element which was about to fail the stress was greater than the resistance, and sliding took place. It might be asked, how did it come about that the bar broke straight across, and not at an angle? In the first place, a great many bars did break at an angle; he had had scores of flat steel bars break like that, and those who had had much experience in testing would know that round bars frequently broke with a shearing cone. The reason why some bars broke across and others at an angle was quite explicable. If he had time he would go into the subject more fully, but he could only reiterate that he considered there was abundant evidence to show that the ultimate criterion of the strength of any material was its resistance to shearing. This of course was followed by many important results. For instance, a round bar with a U-shaped groove turned in it, Fig. 18 (page 23), might be 20 to 30 per cent. stronger than a bar of equal minimum section, as shown by the dotted lines, for the reason that the material above and below the groove resisted the shear, and so reinforced the minimum section. Another practical result was that, supposing *a* was a hole in the plate, Fig. 19 (page 23), the greatest shearing stress was produced in planes at 45° through the hole, and the resistance of these sections to shear determined the strength of the plate. If another hole was put at *b*, the strength was reduced; and it was the resistance to shear of the section through the two holes, and not the resistance to tension of the cross-section through either hole, which determined the strength of the bar. Other instances might be quoted.

The PRESIDENT stated that the author was not present, so that he could not reply to the criticisms which had been passed on his Paper. He ventured to ask Professor Carus-Wilson to supplement his most interesting remarks at the adjourned Discussion on 19th January 1906. It was his great pleasure to propose a hearty vote of thanks to Mr. Izod for his interesting Paper.

The resolution was carried by acclamation.

Discussion on Friday, 19th January 1906.

Professor C. A. Carus-Wilson remarked that his attention had been called to some experiments made with a view to ascertaining the effect of a screw-thread on the strength of a rod, in which apparently the presence of the thread made no difference. If the groove was small in comparison with the diameter of the rod, two effects were obtained which neutralized one another. In the first place there was the effect due to the uneven distribution of stresses over the cross-section, which diminished the strength of the bar; and on the other hand, an increased shearing section was obtained, as explained above, and that increased the strength of the bar. In the case of screw-threads these two effects neutralized one another, and the plain rod was as strong as the threaded rod. The only figures in the Paper which tended against the proposition he had put forward were the results of the tests made by the author on cast-iron. The author's tests showed that the tensile stress, instead of being double the resistance to shearing, was about equal to it. He thought it was very difficult to make an accurate shearing test of cast-iron. The shearing tests he had made himself with cast-iron had given very much lower values for the shear than the author had obtained, but he had always regarded shearing tests of cast-iron with great distrust. Professor Unwin, in his standard book on "The Testing of Materials of Construction," said that the resistance of cast-iron to shearing was imperfectly known, and quoted tests made by Messrs. Platt and Hayward, in which the shearing stress was about half of the tensile stress; and Professor Unwin stated that possibly those shearing resistances were too small. He did not wish to criticise at all adversely the way in which the author had made his tests; he had no right to do so, but he simply said that he thought the state of affairs existing when a shearing test of cast-iron was being made was one of very great complexity, which needed careful examination before any deductions were made from it. Of course, in any case what was commonly called a shear test was a very crude way of getting the resistance to shearing of a material.

(Professor C. A. Carus-Wilson.)

One only had to think of the condition of affairs in a shear test to see that the distribution of stresses must be very far removed from those which would produce a perfectly uniform shear, or even a pure shear, supposing it was uniform. The distribution of stresses in a piece of material which was being sheared was complicated, and the lines of principal shear along which the material would fail were curved in an irregular manner. This was borne out by the author's diagrams and the very interesting photographs which he gave in Plates 1 and 2. In these diagrams the author showed what he called a peculiar knife-edge in the broken section, indicating that the distribution of shear stress was extremely irregular. His own impression was that a shear test only gave approximately accurate results in the case of plastic materials; and that when extremely hard materials were used, which were absolutely non-plastic, as in the case of cast-iron, there was a complicated condition of cross stresses which entirely masked the result one was attempting to arrive at, namely, the true measure of the resistance to shearing.

Professor W. CAWTHORNE UNWIN, Honorary Member, was sure the author had put before the Institution an interesting and useful Paper containing a great deal of valuable data for practical engineers. He had placed on the table for the inspection of the members a shearing shackle which was made at the Central Technical College some years ago, and which did not differ very much from that of the author's. It was made for circular turned rods, and the shear was made to take place between three dies, or, if only a single shear was wanted, between two dies. The only essential difference between it and the author's shearing shackle was, that in Mr. Izod's shackle a strong compression was put on the faces of the plate near the shearing plane by bolts. The author obtained a result, and he (Professor Unwin) also obtained a result, which he did not think was very different, and he did not think anybody could say exactly which shackle gave the result which was most nearly like a pure shear. If the plate was compressed as in the author's shackle, there must be, in consequence of the indentation of the plate in the early stages of compression, a longitudinal

compression normal to the shearing plane. On the other hand, if the plate was free, as in his shackle, that compression disappeared; but he was not prepared to say that the one instrument was better than the other. The author had noticed—it had been noticed for

FIG. 21.

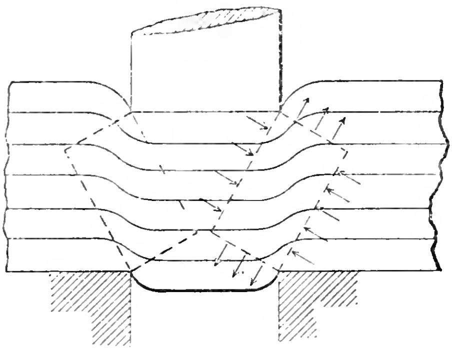


FIG. 20.

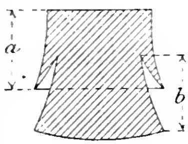


FIG. 22.

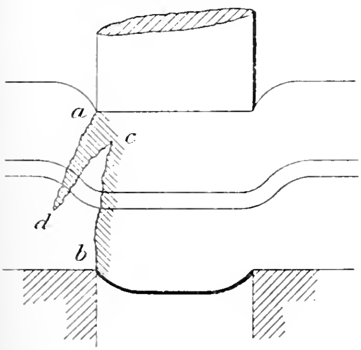
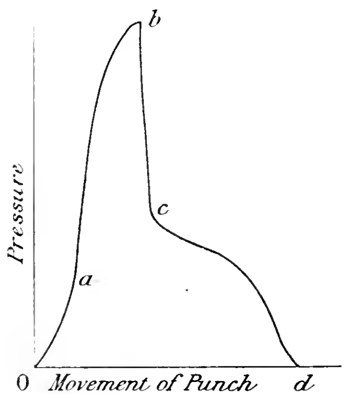


FIG. 23.



many years before—that in a good kind of shear, he did not say a pure shear, a very singular frill was formed, which was seen best in punchings, Fig. 20. Punching was simply a variety of shearing. In a very thin plate part b tended to disappear. In a very thick plate, especially in a plate thick in proportion to the diameter of the

(Professor W. Cawthorne Unwin.)

punching, part *a* tended to disappear. If a die larger than the punch was used then the frill disappeared.

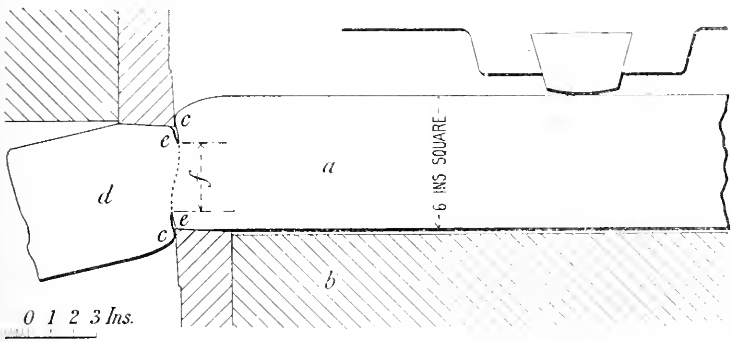
The only objection he had to the Paper was part of the title, which spoke of "pure shear." He did not think there were any means of getting a pure shear by means of a scissor-like action. He was speaking only of the shearing action on ductile materials; he left the question of cast-iron for the moment entirely on one side. If the lines were scribed on the plate before testing it, they were distorted as shown in Fig. 21 (page 27). There was obviously a lengthening of the portions of the plate within the dotted lozenges, and therefore a tension, especially towards the middle of the plate. Hence a crack formed at right-angles to the direction of the strained lines, as in Fig. 22 at *c d*. At the same time, there was a very strong tension at points *a* and *b*, and there was a tendency to form cracks *a d* and *b c*, and he believed that was the explanation of the formation of the frills. That was interesting, because a little studying of the lines would show, he thought, that there was nothing like a pure shear on the plane from *a* to *b*. There was a tension and compression as shown by the arrows in Fig. 21, but not inclined at the angle at which they ought to be for anything like a pure shear.

It might be of interest to say that quite lately some French engineers had been studying punching as a useful workshop test. M. Frémont, in a Paper which he (the speaker) had seen but which he had looked for and could not find; M. Baclé, in a Paper which was read at the Congress at Paris in 1901, and Professor Rejto in a Paper which appeared in "Materialienkunde," had all been studying a punching test; and Rejto especially had done a good deal to connect the result obtained in a punching or shearing test with the tearing resistance of the material. The investigation was a very complex one, and he would not venture to say anything about it that evening, but a step had been made towards connecting the tenacity of the material with the result obtained in the shearing test.

Mr. J. HARTLEY WICKSTEED, Past-President, said he had seen a good deal of actual shearing in shearing machines, and had sheared bars cold up to 6-inch by 6-inch solid section of both mild and

hard steels, the latter of which were rather capricious, as they very often declined to shear through the plane of intensest pressure. He had found that 6 inches thick in hard steel was about as far as it was possible to shear cold, because the pressure on the blades was so great that steelings could not be obtained to stand a greater pressure on the edges. A bar tried all it could to avoid shearing; it tried to bend and pull and to compress and flow rather than to shear. Fig. 24 showed a bar of mild steel lying in position upon bottom steelings; *a* was the billet coming on, and *b* the bolster of the machine. The steelings had now approached each other to the

FIG. 24.



extent of $1\frac{1}{2}$ inches, and still the bar was not severed. All this time the steelings had been compressing their way into the metal, and had also been cutting their way through the metal that had been pulled over at *cc*, and had displaced the piece *d* to the extent of $1\frac{1}{2}$ inches without having severed it. When the steelings had got so far in, the metal at *e* had been removed from the face of what had been opposite it, and therefore there was a cleavage of an equal distance to the displacement. The metal at *e* had been removed from what it used to be opposite to at *c*, and there was such a cleavage that, as nearly as he could find, if the steelings had compressed and entered the metal $\frac{3}{4}$ inch at each side, the crack penetrated another $\frac{3}{4}$ inch at each side, and left only an uncracked piece of metal *f* about half the thickness of the original billet. From that point the two cracks

(Mr. J. Hartley Wicksteed.)
tried to join each other, and as they started off in opposite directions they were obliged to do so by a curve of contrary flexure, joining each other as shown by the dotted line. Out of the whole thickness of the 6-inch bar, he believed only half of it was sheared simultaneously. The fact was that the shearing of a thick piece was not a simultaneous thing like the fracture of a piece under tension, or like the compression of a bar under compression, but was a gradual process. The first thing that happened was that the surface was compressed, and in the next place the surfaces were cut by the cutting edges of the steelings. One surface got past the other so as to establish an initial crack, and then finally about half the bar separated with a shearing effect.

Referring to the Paper where the author said that in mild-steel the shearing resistance was about 75 per cent. of the tensile resistance, and referring to the general rule found in the text-books that the shearing strength of a certain material was about 75 per cent. of the tensile strength, his explanation of the statement was that the area was reduced to 75 per cent. before the shearing took place. The previous process had been one of compression and of cutting. Some of his friends wishing to make rather large shearing tests in a testing machine, he designed an apparatus for shearing in single shear, in order that a larger piece might be done than could be used in double shear with the same power of machine. He accomplished the shearing of bars 8 inches wide and 3 inches thick, and had made several tests upon bars 3 inches wide and $2\frac{1}{2}$ inches thick. The way in which the single shearing was carried out was shown on Fig. 27 (page 31). The way the block tailed down in ordinary shearing could be seen on Fig. 24 (page 29). To prevent this taking place in the testing apparatus, the bar was pushed through and allowed to rest upon a ledge so that the bar, besides being held down at one end, was held up at the other end, Fig. 26 (page 31), the result being that the curve of contrary flexure was not quite so pronounced, because the initial cracks did not run in so much on opposite sides of the plane of cleavage as they did where there was a free end. In making the experiments he took a mechanical record which showed very well what was going on, Fig. 25 (page 31). It showed, for

Material—Basic Steel. Section 3" × 2½" = 7·5 sq. ins.
Max. Load—129·74 tons = 17·3 tons per sq. in. of original section.
Amount of Penetration at Max. Load = 0·55 in.
Total Penetration before Breaking = 0·65 in.
Work Done = 66·95 inch-tons.
Approximate Shear Stress on Ultimate Area = 30·9 tons per sq. inch.

FIG. 25.

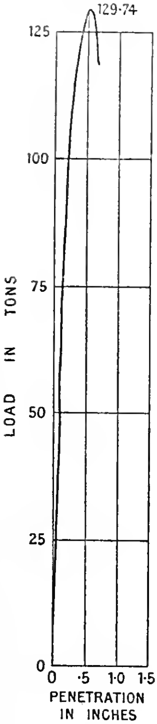
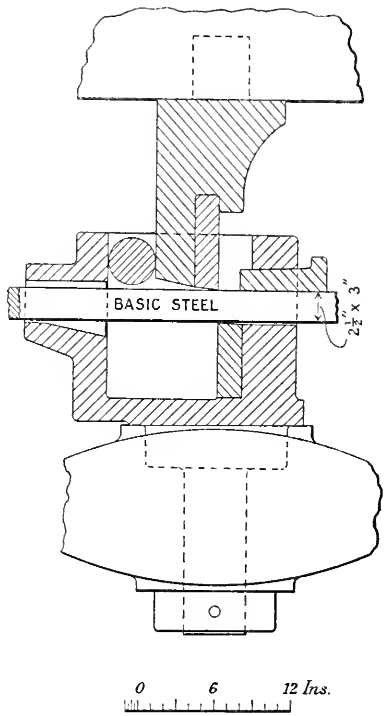


FIG. 26.



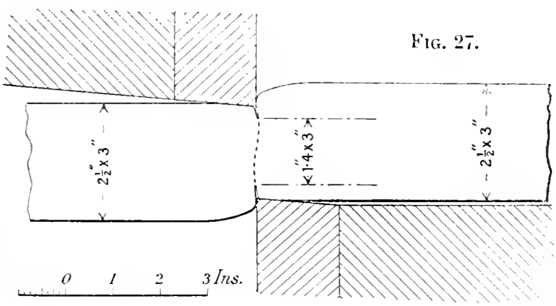


FIG. 27.

(Mr. J. Hartley Wicksteed.)

instance, that in the bar $2\frac{1}{2}$ inches thick the maximum pressure was not reached until the shear blades had approached each other half-an-inch, so that when the maximum load of 129 tons was reached the blades were no longer $2\frac{1}{2}$ inches but only 2 inches apart. It also showed that, before the piece severed, it managed to stand this displacement, the one $\frac{1}{2}$ inch passing the other $\frac{1}{2}$ inch. What had happened was what Professor Unwin had described. All the fibres must have been drawn obliquely in the central region of the bar, and cracked towards the outside; and the result showed that before the piece actually sheared there was 0·65 inch of displacement in the bar. The diagram, Fig. 27 (page 31), showed openings in advance of the shear edges, and the dotted line showed the curve at which the bar would ultimately break.

His point in making the remarks was first of all to show how a good single-acting shearing apparatus could be made, for application to a testing-machine, which sheared the bar in single shear; and, secondly, to show that the process of shearing was a gradual process, that at the beginning the shearing resistance of the bar was much greater than its resistance to compression, and that before sufficient load was applied to shear the whole section the bar was impressed and indented very deeply; and that compression went on until at last the reduction in the area of the bar was sufficient to make the bar more willing to shear than it was to resist further compression.

Mr. C. E. Stromeyer said the Paper had interested him very much, because it indicated that different materials might be expected to behave differently under compound stresses. It had been mentioned in the Paper that the fractures of cast-iron and mild steel differed in character. If he understood the author rightly, cast-iron sheared fractures were directed into the region under the blade pressure, whereas in mild steel these fractures were directed away from this region. Evidently the fracture in cast-iron travelled towards the region where the stress was a compound of two compressions, whereas in mild steel the fracture travelled in the direction where there was either a simple compression-stress or a compound stress consisting of cross compression and tension stresses,

and therefore resembling a shearing stress. This would indicate that mild steel gave way more readily under a compound stress consisting of cross compression and tension than under simple compression or under a compound stress consisting of two cross compressions, and that cast-iron behaved exactly in the reverse way. The only experiments on the subject of compound stresses had been made by Mr. Guest, which he had summarised in his (the speaker's) book on Boilers. The deductions which he had made from Mr. Guest's experiments were that steel whose elastic limit was 18 tons under simple tension would resist about 21·4 tons without giving way, if subjected to two cross-tensions, but would give way at 9·7 tons if subjected to a tension stress in one direction and a compression stress at right angles to it. These results were plotted in Fig. 28 (page 34), in which the radial distances marked on the horizontal and vertical axes represented simple stresses, either tension or compression, whereas radial distances in any of the quadrants represented the greater of two components of compound stresses. The direction of the radiant indicated the ratio of the intensities of the two components. Shearing stresses, in which the components were tension and compression of equal intensity, must lie on the line which, at an angle of 45°, passed through the quadrants bounded by the simple tension and simple compression axes, whereas drum tension lay in the quadrant bounded by the two simple tension axes.

In Mr. Guest's experiments, of which seven lent themselves to a detailed analysis, cylindrical tubes were subjected firstly to simple tension stresses, under which one set gave way at 18 tons per square inch. Other tubes were subjected to circumferential stresses at 13·4 tons produced by an internal hydrostatic pressure to which longitudinal tension stresses were added, which reached 20 tons before the material gave way; other tubes were subjected to similar compound stresses of 18 and 21·4 tons and others to shearing stresses of 9·7 tons. The major components, namely, 18 tons simple tension, 20 tons in a direction inclined at 13·4° to 20° to the axes, 21·4 tons in a direction inclined at 18° to 21·4° to the axes, and 9·7 inclined 45° to the axes. Neither the simple nor compound compression strengths were obtained, but from some experiments on

(Mr. C. E. Stromeyer.)

FIG. 28.

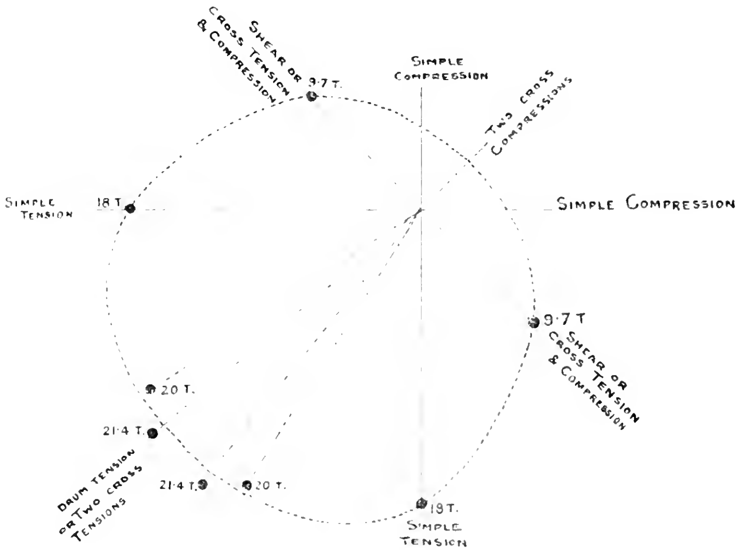
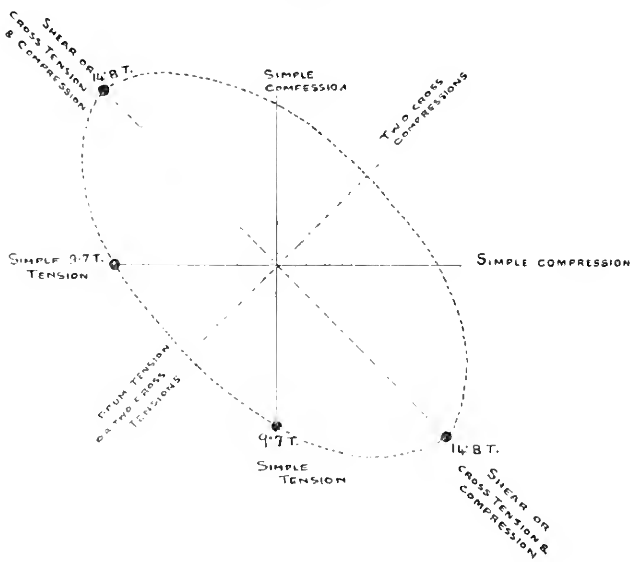


FIG. 29.



flat plates he (Mr. Stromeyer) estimated that mild steel gave way under a cross compression-stress of about 4 tons per square inch; and introducing this value in the diagram, a characteristic compound-stress curve at the elastic limit was obtained for mild steel which was indicated by the dotted line in Fig. 28 (page 34). The dotted line in Fig. 29 represented a similar (ultimate) compound-stress curve for the cast-iron sample A of this Paper, the few radial lengths being taken from the details given in Table 1 (page 9). No experiments on two cross-tensions, as in Mr. Guest's tests of mild steels, had been made with cast-iron, otherwise the dotted curve could have been drawn with greater reliance than was now possible. It was, however, quite evident that the characteristic compound-stress curves of mild steel and cast-iron differed very materially in character, and any attempt to determine for all materials a definite ratio between their tensile and their shearing strengths must prove failures.

The deduction to be drawn from Mr. Guest's experiments on mild steel was an interesting one, but one which he did not intend to carry into practice. It amounted to this: a Lancashire boiler which had dished ends or flat ends stayed by gussets in whose shell there would therefore be both circumferential tension and longitudinal tension ought, according to Mr. Guest's experiments, to be 20 per cent. stronger than a marine-boiler shell whose ends were held by longitudinal belt-stays. This deduction sounded very strange, and he only mentioned it to indicate the importance of studying compound stresses.

It would be very interesting to ascertain how mild steel behaved when it got into a region where there was a double compression. Experiments had been made on the effect of hydrostatic pressure on metals, but he thought they only extended as far as platinum. It appeared that, up to a certain pressure, the density of platinum would permanently increase if it were subjected to hydrostatic pressure; but when a certain pressure was exceeded—he believed the figure was 60 tons per square inch—the density of the platinum was permanently reduced, showing that the material had been disturbed, and that its elastic limit under this particular compound stress had been passed. He thought that compound stresses deserved

(Mr. C. E. Stromeyer.)
looking into very carefully because they occurred in all structures, especially in machinery where the forms were complicated and the external forces numerous.

There were seven compound stresses, which he would not enumerate, but he would mention a few so as to indicate their nature.

There was the compound stress consisting of cross-tension and compression, which was called shear. Then there was what he might call drum-tension, which consisted of two cross-tensions. There was also a negative drum-tension, consisting of two cross-compressions. One might also have the three pairs of sides of small cubes of a solid subjected to positive or negative stresses. If these were equal compression stresses, the compound would be called fluid pressure. He did not know that any experiments except those on platinum just mentioned had ever been made with this compound stress, unless it were the inquiry with regard to minerals and crystals, which indicated that these were capable of flowing under great hydrostatic pressure. There was another interesting compound stress which, because it consisted of a pull in one direction and two cross compressions, might be called wire-drawing stress. The fact that a wire did not tear while being drawn through a die seemed to indicate that the material was weaker under this so-called wire-drawing stress in the hole than under a simple tension stress outside the hole, although here the diameter was reduced. Of cast-iron one might expect that it would be better able to withstand a wire-drawing stress than a simple tension, for it could not be drawn. Whether a compound stress consisting of three tensions was a possible one to experiment on he did not know; it certainly existed in the interior of cast ingots, and heavy gun forgings sometimes burst internally while the outer surface was being removed in the lathe. If the behaviour of various metals under these and other compound stresses were inquired into, mathematicians would soon be able to discover where the stresses had to be looked for.

A remark had already been made that the title of the Paper referred to the behaviour of materials under pure shear. He thought that torsion experiments could be made to represent pure shear better than the experiments given in the Paper. He had pointed out

in his work on "Boilers" how torsion tests could be utilized for shear stress-strain diagrams. The matter was also dealt with in "Engineering." *

The analysis was a fairly simple one and would be best understood by imagining that a cylindrical bar was being twisted through a definite torsion angle and its torsional resistance moment measured, and then turning off a thin outer film, twisting the reduced and therefore weakened bar until the shearing deformation of the outer surface was what it was in the larger bar. The torsion moment would, of course, be less than before. Now imagine the film which was turned off to be added in the form of an independent cylinder, having the original outside diameter, and imagine this cylinder to be torded till the shear angle of its inner surface agreed with the shear angle of the outer surface of the reduced bar, then this additional torsion moment, divided by the mean radius and by the sectional area of the outer cylinder, was the shearing stress in the outer film corresponding to the then existing shear deformation, which was of course equal to the torsion angle of the bar multiplied by the ratio of its radius to length. One could imagine this analytical process to be repeated for increasing shear deformations, and thus obtain a shear stress-strain curve. The practical way of carrying out this process was to obtain a very accurate torsion stress-strain curve, altering the scale of ordinates so that the torsion angles were reduced to shear deformations of the outer surface and the torsion moments were reduced to elastic shear stresses of the outer surface. Reducing the latter ordinates to $\frac{3}{4}$, and adding to the curve thus produced the product of one quarter of the deformation ordinates multiplied by the tangent of the angles of the original curve the true shear stress-strain curve was obtained. Expressed mathematically the process was given by the formula

$$\sigma = \tfrac{3}{4}\sigma_0 + \tfrac{1}{4}\theta \frac{d\sigma_0}{d\theta}$$

Here σ is the shearing stress corresponding to the shearing inclination θ, σ_0 is the shearing stress which would be found at the outer surface if the material were perfectly elastic. This analysis had been

* "Engineering," vol. 58, 1894, page 443.

(Mr. C. E. Stromeyer.)
carried out on one of the carefully recorded torsion stress-strain diagrams of Messrs. Platt and Hayward's Paper,* and it was found † that after passing the elastic limit there was a yield-point or drop in the shear stress-strain curve, just as there was a drop in the tension stress-strain curve of mild steel. He (Mr. Stromeyer) had mentioned this method of obtaining an accurate shear stress-strain curve, because he thought that more attention should be paid not only to this compound stress but to other compound stresses.

He trusted that the question of compound stresses would, if possible, be taken up by the Institution. They occurred in parts of machinery, such as crank-shafts and other complicated forms, although perhaps not so much in boilers, and he thought it was necessary to know what the effects of compound stresses were. If mathematicians were once shown what the effects were, he believed they could work out for engineers where to find them, and engineers would then be able to design machinery more in accordance with the true factor than was possible now. At present engineers went more by ordinary experience, and any part of a machine which showed weakness was made more substantial or a different material was used, but if his suggestion were carried out he thought that engineers would be able, after determining the nature of the compound stresses in various parts of the structure, to decide unhesitatingly whether cast-iron, mild or hard steel, or any of the numerous bronzes, was best suited for that particular piece of machinery.

Mr. WILLIAM H. MAW, Past-President, desired to ask Professor Unwin if, in the punching experiments to which he had just referred, he made any determination of the cubic contents of the burrs punched out, as compared with the cubic contents of the holes from which the pieces came. The reason he asked the question was that some thirty years ago, when a good deal of interest attached to the supposed injury to steel caused by punching, he made a number of experiments on the effect of varying the size of the female die of

* Proceedings, The Institution of Civil Engineers, vol. xc, Plate 10, Fig. 6.

† *See* "Marine Boiler Management and Construction," 2nd edition, page 164, Fig. 123.

the punching machine and the effect on the form of punching obtained with the various sizes of such die. One of the first things noticed in making an experiment of that kind was that the punched burr that came out was of less vertical height than the thickness of the plate; and that deficiency in height seemed to increase as the thickness of plate increased, as the female die was made smaller and as the slowness of the punching increased. With a very thick plate, a very close-fitting female die, and a very slow-action punch, a very material reduction was obtained in the height of the burr. One of the first things that struck him was whether there was any real compression of the burr, that is, whether the specific gravity was altered. He took the specific gravity of a number of burrs, and found they were practically the same as that of the plate. There was a slight difference, but the difference was in the direction of a reduction of the specific gravity of the burrs. In all cases the burr had a specific gravity that was rather less than the plate from which it was taken. Then the question arose: where did that piece of material go to? It was quite evident on examining a punched plate—as probably many members had noticed—that there was a slight rising of the metal of the plate round the hole on the side of the plate at which the punch entered. This bulging of the surface of the plate showed that during the first part of the punching operation pure shear did not occur. There was a flow of the material from that burr into the plate. In the experiments that he made, the material was soft steel, and there was little of the frilling of the burrs that Professor Unwin had noticed. It was present in some cases, but not very much of it. He was curious to know whether, in the experiments Professor Unwin had made, he found that when that curious frilling of the burrs took place, there was less flow of metal than when an ordinary slightly conical burr was produced.

Professor W. CAWTHORNE UNWIN said he could quite confirm what Mr. Maw had said. He had tested the density of the punchings, and so far as there was any change the density was decreased. The volume of the punching was less in thick plates

(Professor W. Cawthorne Unwin.)

than the volume of the hole, and the material which had apparently disappeared had gone into the sides of the plates. That was quite certain. He would like to point out that he had taken a number of autograph diagrams of punching, and that French experimenters had also done the same thing. Punching was simply single shearing, exactly like that which Mr. Wicksteed had described, and in single shearing exactly the same kind of diagram was obtained. Fig. 23 (page 27) showed the general form of the autograph diagram obtained. The first part of the diagram O*a* was concave. This corresponded to the bending of the plate before the pressure of fluidity was reached and indentation began. From *a* to *b* corresponded to the indentation of the plate. The rapid fall *bc* corresponded to the tearing and shearing. Lastly, the irregular line *cd* indicated the frictional resistance to the expulsion of the punching. In a thin plate the convex part *ab* was small; in a thick plate the part O*a* disappeared, and the part *ab* became important.

The PRESIDENT regretted that the author was unable to be present to reply to the various remarks that had been made, and invited the members, before Mr. Izod made his written reply, to write to the Secretary any views they held upon this interesting Paper.

Communications.

Mr. J. POLLOCK BROWN wrote that he had read the Paper with considerable interest, as shear, if it could be got pure, would give a better idea of the quality of material than any other form of stress which was just a record of molecular shear smothered, as it were, in extraneous conditions. On page 7 appeared a statement which he could hardly credit, namely, the results from different sections were practically identical. He thought that that part of the subject merited more than passing mention. If a one-square inch section were put

under shear in two different forms, say $1\frac{1}{2}$-inch deep and $\frac{1}{8}$-inch deep, was it to be understood the results would be the same? It did not seem to him an easy matter to get a pure shear, and perhaps better results might have been obtained by subjecting the samples to double shear in the form of pins well fitted into the holes. He was aware that very uniform results were obtained when testing riveted joints. While comparing tensile with bending and torsional stresses, he had noted results which had led him to compare the quality factors of those tests given in Table 1 (page 9) with the ratio between the stresses given in the last column, and the uniformity corroborated his previous finding, namely that the harder the material the more insignificant the tensile stress became in comparison.

Professor JOHN GOODMAN wrote that he was much interested in Mr. Izod's experiments on the shearing strength of materials, and believed that the results would be of great value to designers, since they were expressed in exactly the manner which draughtsmen and others would readily follow and appreciate. Possibly the more highly theoretical treatment that had been referred to by some who had taken part in the discussion might have yielded a somewhat more regular ratio between the shear stress and some function of the tensile stress, but such a treatment certainly would not have been so useful for the everyday purposes of designers.

An apparatus almost identical with that used by Mr. Izod had been in constant use in the Leeds University Laboratory for many years, and had given entirely satisfactory results as regards the determination of the commercial shearing strength of materials. A comparison of the Leeds tests, which were the mean of a large number, with those obtained by Mr. Izod might be of interest, and was given in Table 3 (page 42).

It would be seen that the results obtained by the two machines were quite closely in accord; the Leeds results given in brackets were obtained from a series of punching tests.

The question of the shearing strength of cast-iron had been referred to by several speakers, and some doubt had been thrown on the accuracy of Mr. Izod's figures, mainly because Messrs. Hayward

(Professor John Goodman.)

and Platt some years ago, with somewhat imperfect apparatus, obtained much lower results; but surely if the accuracy of any results were to be questioned, it should be those which were low rather than those which were high. Every testing expert knew how careful one had to be when testing cast-iron in tension, and if imperfect appliances were used, the results were almost certain to be too low; hence when a careful worker took great precautions to get a perfectly axial pull and thereby obtained correspondingly higher tensile strength,

TABLE 3.

Material.	$\frac{\text{Shearing strength}}{\text{Commercial tensile strength}} = \frac{F_s}{F_t}$	
	Leeds.	Izod.
Cast-Iron	1·18	1·23
Wrought-Iron	0·82 (0·80)	0·75
Mild Steel	0·79 (0·78)	0·78
Hard Steel	0·71	0·68
Gun-Metal	1·13	1·03
Copper	0·73 (0·71)	—
Aluminium	0·65	0·70

his results should be accepted, in preference to others, until someone, by even more perfect apparatus, succeeded in getting still higher results. It not infrequently happened when testing cast-iron in shear that the specimen cracked by bending long before it had sheared; this cracking in some instances might have been mistaken for the true shear. In apparatus such as that used by Mr. Izod it was better to use two separate specimens, each in single shear which overhung from the outer gripping jaws of the shearing tackle, and if these pieces were turned slightly taper at the ends, there was no possibility of bending taking place and a practically pure shear stress was obtained.

They had succeeded at Leeds in punching a clean hole in a cast-iron plate without cracking the surrounding material, and had obtained practically the same ratio between the shearing and the tensile stress as that given in Table 3 (page 42). With the exception of specimens which were defective on account of blow-holes or sponginess, the writer had never had a single instance of a specimen of cast-iron giving a lower result in shear than in tension.

With regard to ductile materials the writer had for years pointed out to students that a comparison between the nominal or commercial tensile strength (which took no account of the reduction in area at the point of fracture) and the shearing strength was liable to give erratic results, but on going more fully into the question and comparing the real tensile strength F_{rt} (as obtained from the last point on an autographic stress-strain diagram) reckoned on the final area of the specimen at the point of fracture with the shearing strength, the results were no more regular than before, probably due to the fact that in shearing tests of ductile materials there was also a reduction in area which appeared to have escaped the attention of all speakers, with the exception of Mr. Wicksteed. Autographic shear stress-strain diagrams at the Leeds University * gave results of exactly the same character as those obtained on another type of recorder by Mr. Wicksteed, which also showed that the shearing or punching dies penetrated to about one-third of the thickness before shearing actually occurred.

In Table 4 (page 44) were given some further shearing results obtained by the writer, and reduced by various methods: (1) The ratio of the shear stress to the commercial tensile stress, namely $\frac{F_s}{F_t}$; (2) The ratio of the shear stress to the real tensile stress (that is, at the point of fracture), namely $\frac{F_s}{F_{rt}}$; (3) Professor Carus-Wilson's method of finding the shear stress on a plane at 45° taken through the stricture of a broken tension test-bar.† If the method (1) were correct, one would expect the ratio $\frac{F_s}{F_t}$ to be

* Engineering, 19th December 1902, page 805.

† Proceedings, Royal Society, vol. xlix, page 243. "The rupture of steel by longitudinal stress," by Professor Carus-Wilson.

(Professor John Goodman.)

TABLE 4.

Material.	F_t	F_{rt}	F_s	Reduction in Area.	θ	$\frac{F_{rt}}{2}$	$\frac{F_s}{F_t}$	$\frac{F_s}{F_{rt}}$	$\frac{F_{rt}\,\theta}{2\,F_s}$
	Tons per sq. in.	Tons per sq. in.	Tons per sq. in.	Per cent.		Tons per sq. in.			
Cast-Iron	10·9	10·9	12·9	Nil	1·00	5·41	1·18	1·18	2·37
Gun-Metal (soft and ductile)	14·9	19·5	14·2	30·7	0·93	9·1	0·95	0·73	1·57
,, ,, (hard and brittle)	12·4	12·8	17·4	3·0	1·00	6·4	1·40	1·36	2·72
Moderately Hard Steel .	48·0	49·8	34·0	7·4	0·99	24·6	0·71	0·68	1·38
Mild Steel	23·6	29·5	18·9	67·5	0·75	11·0	0·81	0·64	1·72
Wrought-Iron (soft) . .	21·7	27·4	17·4	49·8	0·84	11·5	0·80	0·64	1·51
,, ,, (merchant) .	22·6	24·7	24·5	24·6	0·95	11·8	1·08	1·00	2·08
Copper (annealed) . .	14·8	23·7	11·0	65·0	0·77	9·2	0·74	0·46	1·19
,, (hard drawn) . .	17·2	24·1	23·3	47·0	0·86	10·4	1·35	0·71	2·24
Aluminium . . .	8·8	12·7	5·6	45·5	0·87	5·6	0·63	0·44	1·00

constant. It, however, varied from 1·4 to 0·63. Likewise if method (2) were correct, one would expect $\frac{F_s}{F_{rt}}$ to be constant, but it varied from 1·36 to 0·44. Lastly, if Professor Carus-Wilson's method (3) were correct for all materials, one would expect $\frac{F_{rt}\,\theta}{2}$ to be equal to F_s, but the ratio varied from 2·72 to 1.

The values of F_{rt} given below could not be stated with certainty to within 5 per cent., and the value of θ was not certain within 2 per cent.; but assuming that the maximum error did occur, it still left a very great variation in the ratios which might be expected to be constant if the theory were even tolerably complete.

Another matter of interest was raised by Professor Carus-Wilson in the discussion (page 24), namely, the increased strength of grooved bars, which he considered was due to the shearing area at 45°, through such a bar being considerably greater than the area at the same angle through a parallel bar. The writer, however, considered that the increased strength was largely due to the less stressed neighbouring material preventing the material from contracting at the point of fracture, and that the real stress at fracture was very nearly the same in bars of various forms. The mean results of some tests made in the Leeds laboratory were given in Table 5:—

TABLE 5.

Original diameter of bars 1·25 *inch.*
Diameter in smallest section 1·00 *inch.*

Form of Bar.	Nominal or Commercial Tensile Strength. F_t	Real Tensile Strength at Fracture. F_{rt}	Reduction in Area.
	Tons per sq. in.	Tons per sq. in.	Per cent.
Plain	23·1	39·7	43
V	27·3	35·0	10
U	30·7	41·5	23

(Professor John Goodman.)

In the case of the V section the sudden change of stress in the sharp niche had apparently had some weakening effect.

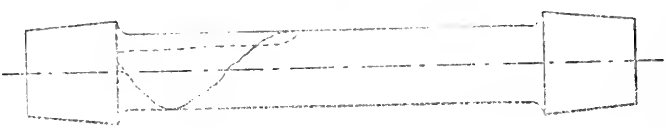
One or two speakers had expressed a preference for torsional tests for ascertaining the true shearing strength of materials, but they had evidently overlooked the fact that the torsion formula only held for perfectly elastic materials; but if the torsion formula were used for the breaking stress, a figure known as the "modulus of rupture" might be obtained, which was of some value in showing roughly the comparative strengths of various materials in shear. The writer's tests gave the following results:—

TABLE 6.

Material.	Commercial Tensile Strength.	Shearing Strength.	Shearing Strength (Modulus of rupture in torsion).
	F_t	F_s	
Cast-Iron . .	11·5	13·0	16·0
Gun-Metal .	13·8	16·0	21·0

Mr. JOSEPH W. HAYWARD wrote that he thought the most satisfactory shearing test was a torsional test upon a round bar. When such a test was applied to cast-iron, fracture invariably

FIG. 30.



occurred along a helix the angle of which was 45°; that is to say, it occurred in the plane across which the tensile stress was a maximum. Fig. 30 was a sketch of such a fracture taken from an actual specimen. The above result indicated that cast-iron had a lower resistance to tension than to shearing. This conclusion was borne

out by the absence of the "cup and cone" formation when cast-iron was broken under tension.

In compression, cast-iron failed by shearing under a stress, calculated on the inclined area, two to two and a half times as great as that which caused failure under tension, but Professor Perry had suggested that, in this case, the pressure between the shearing surfaces might increase the frictional resistance to their lateral motion.

Mr. JOHN McGREGOR wrote that the comprehensive nature of the experiments made the Paper very valuable on all questions of design, and the data given as to the ultimate shear strengths would, he was sure, be found most useful. In considering the actual shearing of materials, the Paper left something to be desired, and if the author had any data of observations on the following two points he would add to its value by including them. The material most subjected to shearing was steel, and after this malleable iron, and when the number of shearing machines in use in steel and iron works, shipbuilding yards, and engineering shops was considered, it would be seen that the question of the shearing of metals was of interest to a large number. Fig. 3 (page 8) and Table 1 (page 9) confirmed the general assumption that, for mild steel and wrought-iron, the shearing strength was practically 25 per cent. less than the tensile strength, and this fact formed a basis for the design of shearing-machine standards for any section of material. An examination of Fig. 12, Plate 1, led him to think that the section shown was just on the point of separation, and the question naturally arose as to the proportionate distance the movable shear-knife must pass through before actual separation of the material took place. For thin sheets, he thought this distance was the thickness of the sheets, but for plates, bars, and the heavier sections it was a less distance, the actual movement of the knife until separation took place having some relation to the depth of the section and the hardness of the material. If the author could give reliable information on this point he would assist in the design of shearing machines as regards the fly-wheel effect necessary and

(Mr. John McGregor.)

the power to be provided to cut any given section. He might mention at this point that observations of a large number of sections while being cut led him to suggest that, as regards mild steel from 1 inch to 4 inches thick, the material was shorn or separated after the movable knife had passed through about one-third of the thickness of the material, but for wrought-iron this distance was greater, while it got less the harder the steel, until it became a very small distance indeed for high-carbon steels.

With regard to the remarks on the preparation of some trial test-pieces (page 7), he would like to know if the author had any data from test-pieces acted upon by different kinds of steelings, that is, by steelings which had the cutting edge more or less rounded. For cutting sheets and thin material there was no question about good sharp steelings being necessary, and for all material there was a fairly widespread belief that blunt steelings added appreciably to the power required for shearing, and so necessitated heavier machines being made. Within reasonable limits he did not think the condition of the steelings mattered very much, so he would appreciate any observations the author had made with steelings which had the cutting edge rounded by $\frac{1}{16}$ inch or $\frac{1}{8}$ inch, or more.

Mr. W. C. Popplewell wrote that he had read the Paper with great pleasure. It was especially welcome because, apart from the fact that the author had made a valuable addition to the data at present available, the subject chosen for the research was one which had been somewhat neglected by experimenters. The neglect of experiment in this direction was probably due to the great difficulty there was in making tests to destruction, in which the stresses causing failure were those of pure shear. There appeared to be two principal reasons for this. In the first place, in shear tests as they were usually carried out, there was a crushing of the material in immediate contact with the cutting edges; this brought about a lateral spreading of the material and consequent reduction of the shearing area. At the same time the line of action of the resultant shearing force might be thrown farther away from the cutting edge, so that there was a

bending moment on the cross-section of the specimen at the cutting edge, which bending moment was of unknown magnitude and helped to cause failure of the specimen. To reduce the intensity of the bearing pressure and the liability to crush the material in immediate contact with the edges, the specimen should be made wide relatively to the thickness. The bending action in the case of ductile materials could not be eliminated, but could be kept within certain limits by making the free length of specimen supported between the fixed dies as short as possible.

The lateral spreading might be partly prevented by supporting the specimen all round, as when it was turned and fitted tightly into circular holders. The disadvantage of this plan, however, seemed to be that the intensity of the bearing stress was made relatively greater. Wide rectangular specimens were probably the most suitable, and the writer thought that better results might be produced by fixing the specimen into dies which fitted the bar at the sides as well as at the top and bottom.

The writer had used two sets of shearing tackle somewhat similar to that described by the author, one at the Yorkshire College, and the other at the Manchester School of Technology. Both were made after the pattern described by Professor J. D. Johnson, late of the University of Wisconsin. The latter of these was fitted with hardened-steel cutting edges which could be removed when necessary. All the parts were made of steel. The chief difference between this and the apparatus described in the Paper lay in the comparative narrowness of the part marked d in Fig. 1 (page 6), being $2\frac{1}{8}$ inches instead of about 4 inches in the author's apparatus. This portion d was made a very close fit between the fixed dies, so that it was only just possible to insert a piece of the thinnest paper in the joint.

The only way in which to subject material to shear stress pure and simple appeared to be in torsion. The writer had found that at the point of fracture of a shaft of ductile material the stress in the material was sensibly uniform throughout the section, and was given by

$$f = \frac{12\ T}{\pi\ D^3},$$

Mr. W. C. Popplewell.)
where T is the torsional moment producing fracture, D the diameter of the specimen, and f the shear stress required. In torsion the material under stress was supported wherever it required support; there was no bending action and there was no local crushing of the material caused by the bearing pressure. The ideal form of shear specimen would seem to be a short hollow shaft of relatively large diameter subjected to a torsional moment. The carrying out of such a test would of course be too costly to allow of its use for commercial work, but it was the only way in which fracture of a ductile material could be effected under a stress which was one of pure shear. The writer's experience of shear tests led him to think that the form of apparatus described by the author was the most convenient one available for commercial testing if only the moving dies were made a little narrower. It was generally admitted that the loading of rivets, the pins of knuckle joints and similar parts, never resulted in simple shear stress, but always gave rise to a certain amount of bending.

Mr. Izod, in replying to the discussion, desired first to say how much he appreciated the generous treatment by the Members of the Institution of what he felt to be a rather incomplete Paper, and he only wished more time had been available when carrying out the experiments to allow of further information being obtained, which would have enabled him to answer fully several of the very important questions raised during the discussion.

Professor Lilly and several other Members had queried the justification of the use of the term "pure shear," and the author realised that a better term might have been applied. The test which the experiments were intended to reproduce was rather a direct shear, such as would be met with in practical working, than the pure shear sought for by a torsion test.

Professor Lilly also considered (page 20) that the ultimate shear strength of a test-bar would vary with the ratio of width to depth, and quoted Mr. Wicksteed's tests in support of his remarks. The author had made experiments in this direction, which were referred to on page 7, and had found that the difference in the results obtained over a large number of test-pieces with a widely varying ratio was

almost negligible, and consequently this point was only given a passing mention, whereas it should perhaps have been more established.

The author agreed with Professor Lilly that the addition of compression tests would have been of value (page 21), and regretted inability to submit any; but he could not agree with the rule laid down for the order in which the various strength-tests would rank, as although the rule might hold with one class of annealed material, yet he thought that comparative tests of cast-iron and aluminium would disprove the theory.

Professor Carus-Wilson had raised a point (page 22) to which the author was not able to reply fully, beyond saying that the *actual* tensile strength at rupture was a more arbitrary figure than the maximum tensile strength, and could be made to vary within wide limits for the same material, as most experimenters would confirm. A more complete answer to Professor Carus-Wilson had been given in Professor Goodman's communication (page 41), and the actual experience of the latter seemed to bear out the author's statement as to the comparative merits of the two tests so far as strength ratios were concerned.

The author was in complete agreement with the remarks on the nature of tensile fractures, and he had found from extended experience with every class of material that if the nature of the material were such as to admit of the "sliding" action of the molecules, that is, if there were any slight measure of ductility present, the tensile fracture was nearly always either at an angle or had a cup-shaped fracture; even a very flat test-bar of mild steel would always show signs of either a recess on one of the broken pieces or a fracture line at nearly 45° to the axis of the bar.

Professor Carus-Wilson queried the accuracy of the results on the shear strength of cast-iron (page 25), and the author was inclined to agree that the cross-stresses set up in a material such as cast-iron under the shear tests carried out for the Paper might influence the shear strength, yet for practical purposes the cross-stresses must be allowed for, as they were nearly always present, and the ultimate resistance to shear of cast-iron, as found from the

F 2

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experiments, might, in the author's opinion, be safely taken for designing purposes.

Professor Unwin had given a very lucid explanation of the frill formed at fracture in some of the materials tested (page 28), which explanation agreed substantially with that put forward by the author, although there was undoubted evidence that the severest stresses were not at the centre of the lozenge mentioned by Professor Unwin, but nearer the point where the material was indented by the knife-edges, which evidence was borne out by the fracture of the specially-treated phosphor bronze in Fig. 17, Plate 2. The lozenge there was an actual fact, but the material has not been affected at the centre. The author would supplement Professor Unwin's remarks on the value of shear tests as a workshop guide to the selection of materials, by saying that in his opinion they were far more reliable than tensile tests, and this opinion was borne out by remarks made by Captain Sankey on Professor Unwin's Paper before the Institution of Civil Engineers (November 1903).

Mr. Wicksteed had called attention to the statement, found in many text-books, where it was laid down as an approximate rule that the Ultimate Shear Strength of a material was 75 per cent. of the Ultimate Tensile Strength, and gave as an explanation that the area was reduced to 75 per cent. of original area before shearing took place (page 30). This 75 per cent. was no doubt a sufficiently accurate figure to take for the irons and steels more generally used, but an examination of Table 1 (page 9) would show that this explanation was not quite correct; for instance, in the tests of Swedish crucible steel the indentation before fracture, which represented the reduction of area mentioned by Mr. Wicksteed, was almost directly proportional to the elongation percentage which varied from 43·0 to 10 per cent., but the ratio $\frac{F_s}{F_t}$ varied only from 74 to 62 per cent.

The author had tried to prove Mr. Wicksteed's explanation of the ratio $\frac{F_s}{F_t}$ in a practical manner, as shown by the curve in Fig. 6 (page 13), but though the results had been somewhat

promising at first the final collection of results pointed to there being a further influence than the reduction of area, affecting the ratio $\frac{F_s}{F_t}$. It would have added greatly to the value of Mr. Wicksteed's remarks if the complete tensile figures could have been given for the single shear test of Basic Steel (page 31).

Mr. Stromeyer had noted correctly the opposite directions which the fracture lines took in cast-iron and mild steel when under a shear test (page 32), and no doubt the explanation which he had given of the compounding effect of the stresses was the correct one. The influence of compound stresses on the design of structures had not been sufficiently considered, and the author wished he had been able to bear the point in mind when making the tests, as he felt certain that a proper study of multiple stresses, and their effect, would give a clue to the solution of many inexplicable problems in the fracturing of materials under stress.

Mr. Pollock Brown had asked whether the influence of the cross-section of the bar would not be felt on the results, should, for a given cross-sectional area, the depth vary from $1\frac{1}{2}$ inch to $\frac{1}{8}$ inch (page 40), and the author considered that it would be very difficult to ensure uniformity of shear stress over a very wide test-bar where the ratio of $\frac{\text{depth}}{\text{breadth}}$ was small. Although he had made tests with bars varying widely in this ratio, yet there had been no difference in the shear strength obtained from a given material, and he was of the opinion that, provided an absolute uniformity of stress could be obtained over the whole area, the ultimate shear stress on a given area would be almost constant whatever the form of cross-section.

Professor Goodman's remarks and the Tables of results which he had put forward were of very great interest, and very much appreciated by the author, as they were the confirmation of the results put forward in the Paper. Professor Goodman had called attention to the difficulty of testing cast-iron in tension (page 41); and the author would like to say here that the tensile tests, carried out in the cast-iron for the experiments enumerated in the Paper, were made very carefully to ensure an absolutely axial pull on the

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test-piece; and the close agreement of the tensile figures, obtained from the same brand of material, pointed to the fact that bending stresses had been almost completely eliminated. The author was pleased to see that Professor Goodman's figures for shear in cast-iron were in such close agreement with the figures in the Paper, as it was to determine the shear value of cast-iron that the experiments were first undertaken, and the results obtained were so different to what one had been led to expect that check figures were of great value.

With regard to the desirability of taking the tensile strength on the reduced area into account when making comparative tests, the author agreed with Professor Goodman that if this figure were to be used, it would necessitate a similar value being obtained for the shear tests, and even when these figures had been obtained and the results compared, the author was of the opinion that no closer agreement would be found than in the figures put forward in the Paper, where all stresses were calculated on original areas, which calculation must always be used in designing structures or parts of machines.

Mr. Hayward had deduced from his torsion tests of cast-iron that the resistance of cast-iron to tension was less than its resistance to shearing (page 46), and thus confirmed the results put forward in the Paper, where the high shearing resistance of the cast-iron was very marked.

Mr. McGregor had suggested a possible modification in the design of shearing machines (page 47), based on the fact that complete separation of the material under a shear stress took place before the knife-edges passed one another. The author did not think such modification would be of very great value, as it would generally be found that shearing machines were used to shear plates or bars of a wide range of thickness, and the advantage in designing a machine to shear one particular thickness and one particular brand was questionable; further, a complete stroke of the knife-edges which ensured that they passed one another would leave a somewhat cleaner face on the material sheared than if the knife-edges were only arranged just to separate the material. The proportional

distance moved by the knife-edges to ensure separation of the material had been given by Mr. McGregor nearly correctly.

With regard to the influence of sharp knife-edges on the material sheared, the author agreed with Mr. McGregor that a small radius on the knife-edges would not add greatly to the power required to shear a given section, but he would advocate sharp and clean knife-edges wherever possible, as with a blunt steeling the material in the neighbourhood of the fracture line would be deformed and distorted very much more than if a clean sharp edge were used which started to penetrate and sever the outer fibres of the material almost directly the load was put on.

Mr. Popplewell had called attention in his remarks (page 48) to the importance of preventing a bending stress being set up between the opposing knife-edges, and the author would say that in the machine which was used for the experiments described in the Paper, the centre or moving knife-edge *e*, Fig. 1 (page 6), which was carried by the middle block *d*, was made an exact fit between the fixed knife-edges *b*, so that the shear stresses induced when the knife-edges moved towards each other was as nearly as possible in the same plane. In the preliminary experiments which the author had made he had noticed the tendency to spreading of the ductile materials, and had consequently adopted a relatively wide test-piece as a standard for the experiments, which agreed with the proposal made by Mr. Popplewell.

WORM CONTACT.

BY MR. ROBERT A. BRUCE, *Member*, OF LEEDS.

Though the subject of worm-gearing has been less thoroughly explored than that of spur-gearing, it might nevertheless be anticipated that little remains to be said on either from a purely theoretical point of view. Experimental investigation of the actions involved in worm-gearing has been singularly incomplete, but many writers have contributed to the theory of the subject. In spite of what has been written, some of the most interesting aspects of the question have been overlooked or ignored, with the result that there is no single source from which a complete account of the action of worm-gearing can be gathered. The present Paper is intended rather to cover some of the more obvious omissions than to give a complete account of this form of gearing. A full explanation would be impossible within the compass of a Paper of reasonable length.

The comparative completeness of the theory of spur-gearing is due to the fact that the whole action of such gears may be studied in a single plane perpendicular to the axes about which motion takes place. The successive positions of the tooth-profiles in this plane, though not capable of continuous representation on a plane diagram, may be drawn at close intervals, and a tolerably clear conception of the motion may be gathered by the aid of a corresponding series of figures.

DOUBLE-THREADED R.H. WORM, 4″ pitch, 4″ outside diam., 3″ pitch diam.

FIG. 1.—*Transverse Section.*

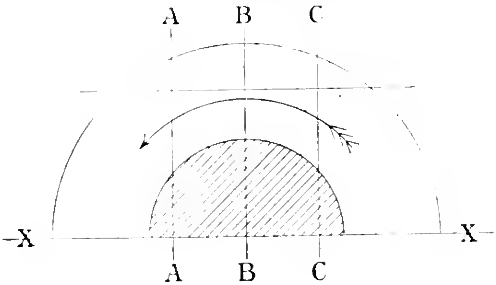


FIG. 2.—*Section on* BB.
(As seen from left of BB in Fig. 1.)

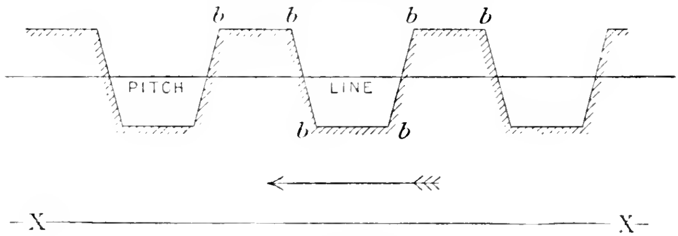


FIG. 3.—*Section on* AA.
(As seen from left of AA in Fig. 1.)

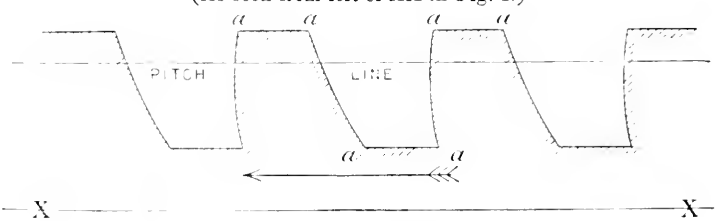


FIG. 4.—*Section on* CC.
(As seen from left of CC in Fig. 1. "Obverse" of *aaa* in Fig. 3.)

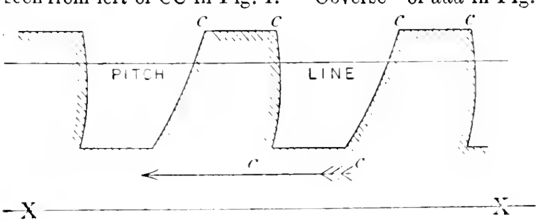


FIG. 5.—*Generation of the central profile of Worm-Wheel Teeth.*

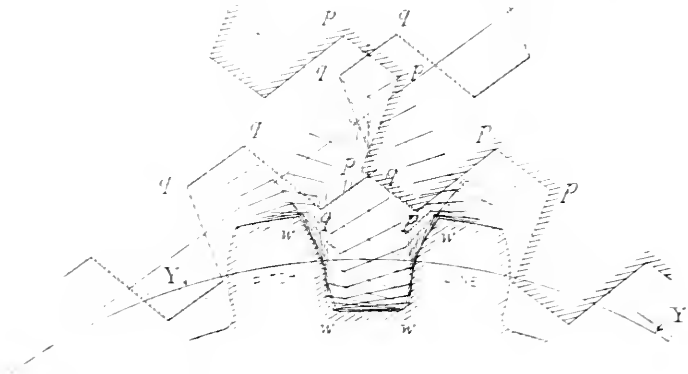


FIG. 6.—*Generation of Worm Teeth profiles in plane* AA (FIG. 3).

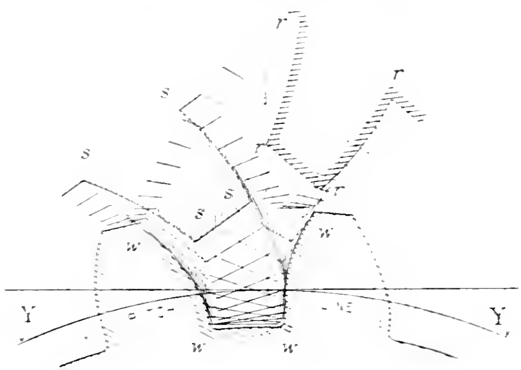
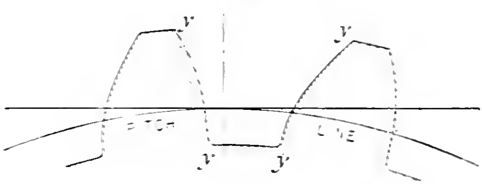


FIG. 7.—*Section of Worm-Wheel in plane* CC (FIG. 4).
("Obverse" of *wwww* in Fig. 6.)



In the case of worm-gearing, the motions of rotation are about axes at right angles, and at the outset some device or artifice is required in order to bring the motions within the range of plane diagrams. If attention be confined to any plane section of a worm parallel to its axis, and the worm itself is rotated whilst the plane remains stationary, it is found that the profile of the section remains the same, but changes its position, advancing uniformly in a direction parallel to the axis at a definite rate, one revolution of the worm causing a translation parallel to the axis through a distance equal to the pitch.

Thus Fig. 1 (page 58) represents a transverse section of a double-threaded right-hand worm, 4 inches outside diameter, 3 inches pitch diameter, 4 inches pitch. The section on a plane through the axis is shown in Fig. 2, the observer being situated on the left of BB in Fig. 1. The profile remains unchanged in shape as the worm rotates, but is translated from right to left as shown by the arrow. Figs. 3 and 4 are respectively sections by planes AA and CC, the observer being situated in each case to the left of AA and CC in Fig. 1. As the worm rotates the same constancy of form, combined with a definite rate of translation, is seen to occur. In order to study the action of a worm gearing with a worm-wheel, it is only necessary to choose BB so that it is the plane through the centre of the worm-wheel. AA, BB, and CC, will then be definite planes in the worm-wheel perpendicular to the axis about which it rotates. The tooth-profiles of the worm-wheel in any particular plane, such as BB, must be such that they would correctly gear with a rack of the form *bbb*, in Fig. 2. Similarly the tooth-profiles of any plane section AA must be such as to gear correctly with a rack *aaaa*, Fig. 3. The plane whose trace is XX must also remain at a constant distance from the axis of rotation. According to this view any section of a worm-wheel by a plane perpendicular to its axis is the conjugate of a rack whose profile is the section of the mating worm in the same plane. In other words, the profiles of the worm-wheel teeth are the envelopes of all the possible successive positions of the worm-teeth which the latter can assume when working in proper relation to the former

In Fig. 5 (page 59) the statement just enunciated is illustrated, several successive positions of the central section—that is, the section in the plane BB of Fig. 1—of the worm are shown in proper relation to the worm-wheel.

The profile of the worm-wheel is seen to be the envelope of the various outlines of the section of the worm-thread. The outline of the worm-thread, in moving from the position *qqqq* to *pppp*, sweeps out the profile *wwww*, which represents a boundary within which it cannot enter, but every part of which it is forced at some time to touch. The central section of the worm yields a symmetrical profile *bbbb*, Fig. 2 (page 58), and the conjugate section of the worm-wheel is also symmetrical, Fig. 5 (page 59). All other sections of the worm by planes, such as AA, or CC, parallel to BB, yield unsymmetrical profiles, and the conjugate worm-wheel profiles are also unsymmetrical.

Thus in Fig. 6, *rrrr* represents a section of the worm-thread by the plane AA, Fig. 3, in one of its proper positions relatively to the worm-wheel whose pitch line is YY; *ssss* also represents the same worm-thread in another possible position, and sufficient intermediate positions of the profile have been drawn to show the unsymmetrical profiles of the worm-wheel teeth, which, as stated before, are merely the envelopes of the successive positions assumed by the section *aaaa*, Fig. 3, of the worm-tooth.

Fig. 7 (page 59) represents a section of the worm-wheel by the plane CC situated on the side of BB opposite to AA and at the same distance from it. It should be noticed that the sections *aaa*, *ccc*, in Figs. 3 and 4, are sections of the worm-threads by planes symmetrically situated with reference to the central plane BB, and that either may be regarded as the obverse of the other. That is to say, *ccc*, Fig. 4, presents the same appearance to an observer in front of the plane of the diagram as *aaa*, Fig. 3, presents to an observer situated at the back of the plane of the diagram. In the same way the section *yyyy*, Fig. 7, which is the conjugate or envelope of the successive positions of *ccc*, Fig. 4, is merely the obverse of the section *www*, Fig. 6, which is the conjugate of *aaa*, Fig. 3. Regarded in this way the whole surface of the worm-wheel is realisable, for it is clear that the positions of the planes AA, BB, in Fig. 1, have been

selected in a perfectly general manner. It should be noticed that, as the plane of section is removed further away from the central section, there is an increasing tendency of the worm-thread to become skewed or distorted, leading to a similar tendency on the part of the conjugate profile of the worm-wheel teeth. The effects of increasing the pitch, or decreasing the pitch diameter of the worm, are precisely similar, skewing or distortion being in each case increased. These statements will become clear on studying Figs. 8 to 13 (page 63).

Fig. 8 represents a quadrant of the transverse section of a worm. BB is the trace of a plane containing the axis, and DD and EE are the traces of planes parallel to BB.

In Fig. 9 the shaded profile *dd* represents the section of the worm by the plane DD, *bb* being the section by the central plane.

In Figs. 9a and 9b the effect of doubling and then trebling the pitch is clearly shown, the tendency to skew being very marked as the pitch is increased.

In Figs. 10, 10a and 10b, sections in the plane EE of Fig. 8 are exhibited in conjunction with the central section, and the effects of departure from the central plane and increase of pitch are illustrated by the increasing tendency of the sections *ee* to become distorted.

Figs. 11, 12 and 13, are sections of a worm of double the pitch diameter of Fig. 8, the pitch and the form of thread remaining unchanged. Fig. 13 compares in all respects except pitch diameter with Fig. 9b, the pitch and distance of the plane of section from the central plane being identical. The effect of increasing the diameter is to regularise very much the profile of the sections in planes parallel to the central plane.

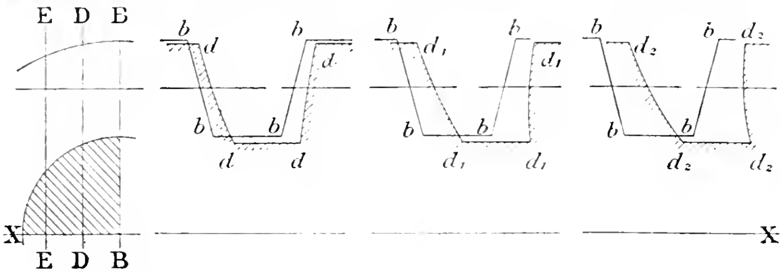
Fig. 13 may be compared with Fig. 10b, and the effect of increasing the diameter is seen to be equally marked in the case of sections by the plane EE. These illustrations will serve to explain the general tendency of the forms assumed by correctly shaped worm-wheels. Valuable as it is that correct notions on these points should be current, they are not of immediate practical importance.

Though accurate machine methods of producing worm-wheels have been known for at least seventy years (Sir J. Whitworth patented his hobbing machine in 1835), nearly all worm-wheels in

Diagrams showing increased Distortion with increased Pitch.

Three Sections on DD (Fig. 8).

FIG. 8. *Transverse Section.* FIG. 9. *Section of Worm.* FIG. 9a. *Pitch doubled.* FIG. 9b. *Pitch trebled.*



Diagrams showing further Distortion as Plane of Section is removed from Central Plane.

Three Sections on EE (Fig. 8).

FIG. 10. *Section of Worm.* FIG. 10a. *Pitch doubled.* FIG 10b. *Pitch trebled.*

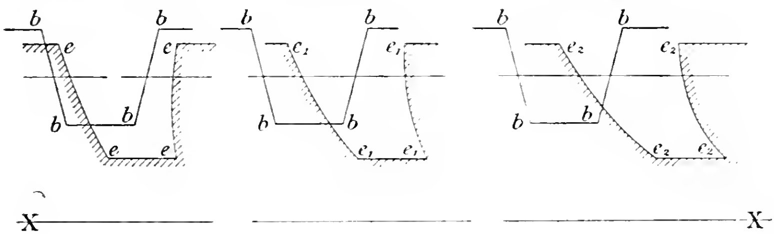


FIG. 11. *Transverse Section.*

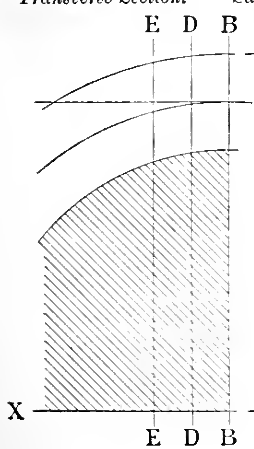
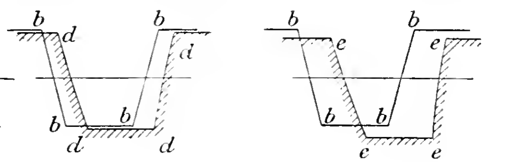


FIG. 12. Compare Fig. 9b. *Same pitch. Diam. doubled.*

FIG. 13. Compare Fig. 10b. *Same pitch. Diam. doubled.*



Diagrams showing diminished Distortion with increase of diameter of Worm.

common use till within late years were cast from wooden patterns. The production of the pattern was seldom dependent upon the previous accurate determination in the drawing-office of the correct profiles of its various sections. The most expeditious method in vogue was to form an approximate pattern of the worm-wheel and mount this upon a vertical stud carried on the slide-rest of a lathe, so that its central plane was horizontal and level with the centres. The actual worm (or a duplicate of it cut in lead) with which the wheel cast from the pattern under construction was to gear, was mounted between the centres of the lathe and the two were brought as nearly as possible into gear. The rotation of the worm which was covered with "marking," in the partially formed pattern, marked the "high points," which were then carefully removed by the pattern-maker, and this process was continued till the bearing of the worm in the wheel was judged sufficiently good, and the correct centre distance was reached. This process, tentative and tedious as it may appear, is performed at a less cost and leads to better results than the method of determining the correct sections of the teeth on various parallel planes and shaping the teeth to the marked lines with the aid of intermediate templates. On the other hand, the various methods by which worm-wheel teeth are cut do not require accurate predetermination of the form of the teeth. So that, however produced, a correct knowledge of the forms of the teeth is necessary rather for the *comprehension* of the finished article than for its production.

A much more important question now presents itself. Given a perfectly formed worm-wheel and its mating worm, what is the nature and extent of the contact that takes place, and how are these affected by the proportions assumed? It is evident that a knowledge on these points must be gained before a really satisfactory basis for determining the proportions of worm-gearing for a given load or duty is arrived at, and, until some satisfactory theory is developed, purely empirical methods must be used.

In developing the theory which follows, the method of procedure is to examine what takes place in various planes parallel to the central plane of the worm-wheel. And, as has been already pointed

out, the action of the sections of the worm and worm-wheel by such a plane is precisely analogous to gearing together a rack and a wheel. When a rack-tooth is in contact with an engaging wheel-tooth the common normal at the point of contact of the tooth-profiles must pass through the pitch-point or point of contact of the pitch-lines. This is the fundamental condition which must be obeyed by any profiles whatever which are suitable for correct gear-teeth. This statement needs no formal proof, for at any moment the correct motion of the pitch surface of the wheel relatively to the rack or that of the rack relatively to the wheel is one of rotation about the pitch-point as virtual centre; any other disposition of the surfaces of the teeth in contact than that stated, would therefore lead either to their separation or interpenetration. Thus in Fig. 14 (page 66) the pitch-line of the rack is pR; that of the wheel being pW, which touches pR at the pitch-point p; rr is one position of a rack or worm-tooth. The point at which contact takes place can now be readily determined, for, if a normal pa be drawn from p to rr, a is the only point which fulfils the condition laid down. WW, the profile of the wheel-tooth, must also touch rr at a, and pa must be normal to it. On this condition alone is rotation about the instantaneous centre p possible. As a rack-tooth passes through all its stages of contact with an engaging tooth, the position of the point of contact is continually changing, and relatively to the pitch-lines its path is determinable and is termed the path of contact. The path of contact for any particular rack-tooth can be readily found as follows: r_1r_8 is the profile of the driving side of a rack-tooth, and p_1p_8 is the pitch-line, Fig. 15 (page 66). Normals p_1r_1, p_2r_2 . . . p_8r_8, are drawn at intervals to cut the pitch-line at p_1, p_2 . . . p_8. When contact takes place at r_1, p_1 must coincide with the pitch-point; similarly when contact is at r_2, p_2 coincides with the pitch-point. If therefore, as in Fig. 15a, the normals and the profiles are redrawn in the successive positions, when contact takes place at r_1, r_2 . . . r_8, a series of points on the contact path will be obtained, and a fair curve through these gives the contact path r_1 . . . r_8, Fig. 15a. The shape of the contact path depends solely upon the shape of the rack-tooth. Thus in Fig. 15a a rack-tooth convex with regard to the mating tooth has a curved

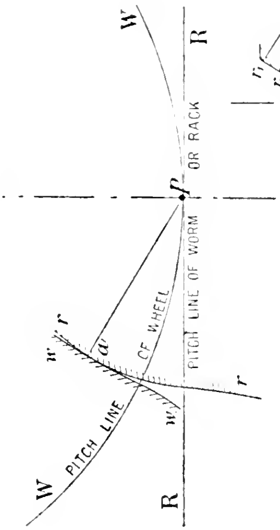


FIG. 14.—*Illustration of Fundamental Condition of Contact of Profiles*

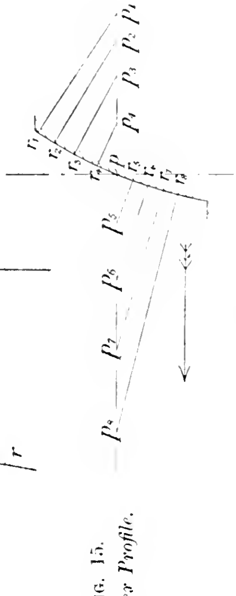


FIG. 15. *Convex Profile.*

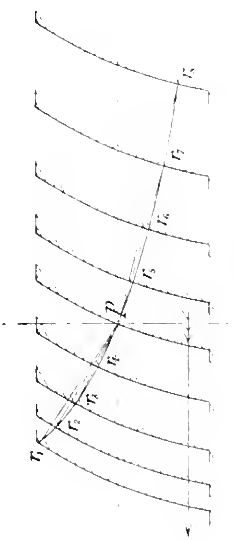


FIG. 15a.—*Contact Path for Convex Profile.*

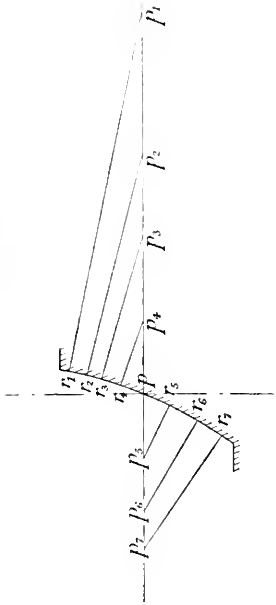


FIG. 16.—*Concave Profile.*

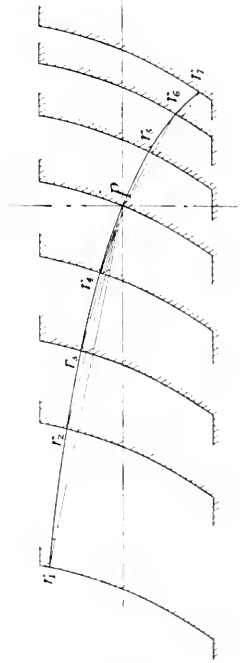


FIG. 16a.—*Contact Path for Concave Profile.*

contact path concave towards the centre of the mating gear. If however a rack-tooth is concave on the side of the mating tooth, the path of contact is curved so as to be convex towards the centre of the mating gear, as in Figs. 16 and 16a (page 66), whilst a straight line rack-tooth has a straight line path of contact. The curvature of the contact path is greater or less according as the curvature of the profile of the rack-tooth is greater or less, and its inclination to the pitch-line is also greater or less according as the inclination of the rack-tooth profile is greater or less.

The limitations of the paths of contact are determined in general by its intersections with the paths of the extremities of the mating tooth-profiles. Contact commences at the intersection of the contact path with the circle limiting the worm-wheel teeth, and ends at its intersection with the straight line through the tips of the worm-teeth. In certain cases, however, the path of true contact is considerably abridged by reason of interference. In order that the path of contact may be determinable for any plane section selected, it is necessary to know when interference is likely to occur, and for this purpose it is necessary to study in greater detail the method of obtaining the conjugate of any given rack or worm profile.

In Fig. 14 (page 66) the line *ap*, which is a normal of the rack-tooth, is also a normal of the wheel-tooth at the point of contact, and the same holds good for any other point of contact.

In Fig. 17a (page 68) r_1p_1, r_2p_2, etc., are normals of the rack-profile r_1r_{11}, when r_1, r_2, etc., are points of contact, and p_1, p_2, etc., coincide with the pitch-point P. Hence if WP (Fig. 17b) is the pitch-line of the wheel gearing with the rack whose profile is r_1 r_{11}, points w_1, w_2, etc., can be obtained on the conjugate profile which will come into contact with the points r_1, r_2, etc., of the rack-profile as follows:—

Make the arc p_1 P, Fig. 17b, equal to the line p_1 P, Fig. 17a, and draw p_1 w_1 equal to p_1 r_1 and inclined to the radius p_1 O at an angle equal to Op_1r_1 in Fig. 17a. Find p_2 and w_2, etc., in a similar manner.

It is obvious that if P in Figs. 17a and 17b were brought into coincidence and the pitch-lines were brought into their proper

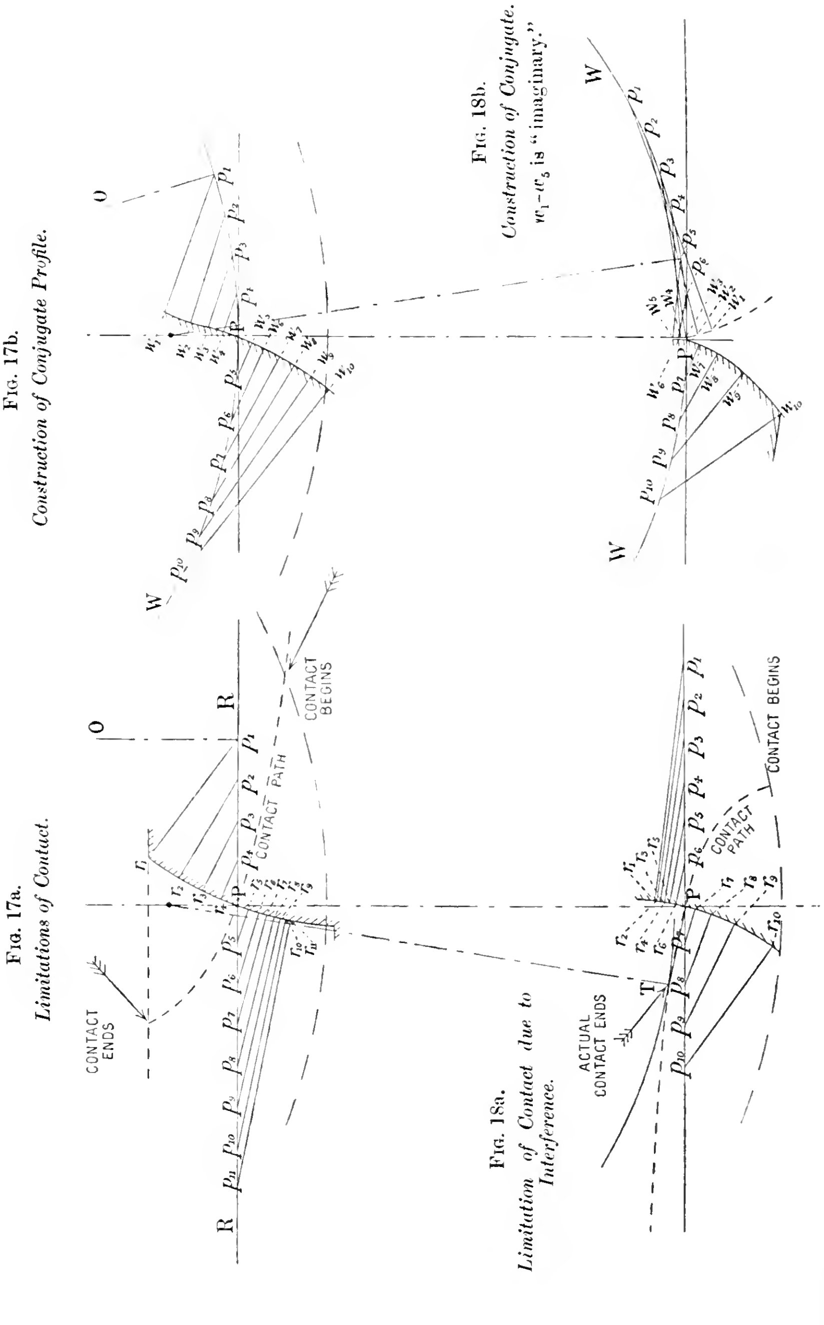


FIG. 17a. *Limitations of Contact.*

FIG. 17b. *Construction of Conjugate Profile.*

FIG. 18a. *Limitation of Contact due to Interference.*

FIG. 18b. *Construction of Conjugate.* w_1–w_5 is "imaginary."

relative positions so that p_1, p_2, etc., successively coincided at P, then w_1 would coincide with r_1, and $w_1\ p_1$ with $r_1\ p_1$; also in its turn w_2 would coincide with r_2, and $w_2\ p_2$ with $r_2\ p_2$, so that w_1 is one point, and w_2, w_3, etc., other points of the conjugate profile. This method of using the normals to construct the conjugate of the rack-profile is therefore an alternative to the method of envelopes already described. It is evident in Fig. 17a that as the lower part of the convex profile is approached the normals greatly extend in length, and if they are drawn for portions below r_{11}, the direction of the normal will ultimately be parallel to the pitch-line, and hence will never meet it. It will now be impossible to find any point on the conjugate profile which will come in contact with a point in the profile from which a normal parallel to the pitch-lines is drawn. When, therefore, the path of contact becomes parallel to the pitch-line of the rack, further contact becomes impossible.

A limitation in the other direction is illustrated in Figs. 18a and 18b. The rack-profile is here concave and the path of contact is such that a circle concentric with the pitch circle touches it at T. Contact beyond this point T cannot take place. For if the construction already described be applied in Fig. 18b to find the conjugate profile, it is found that the resulting curve has a cusp and that the second branch of the curve $w_5\ w_1$ corresponding with that portion of the contract path beyond T, is of such a character that, though the mathematical relationships hold good, physical contact is impossible. If the case be carefully examined, it will be seen that contact between the branch $w_5\ w_1$ and the rack $r_1\ r_5$ would take place on the opposite side of $r_1\ r_5$ to that on which contact occurs between the portions $w_5\ w_{10}$ and $r_5\ r_{10}$. The actual contact path therefore is liable to limitations in two ways: (1) through interference, and (2) through the limitations of the mating teeth themselves. When contact ends through interference, the points at which contact vanishes are those at which the contact path coincides in the direction with the motion of either of the moving members, that is, where the contact path becomes parallel to the straight pitch-line or is touched by a circle concentric with the circular one. In the second case, as already stated, contact ceases at the points of

intersection of the contact path and the paths of the extremities of the tooth surfaces.

By the method just described, the contact path for any section of a worm parallel to the middle plane can be found (*for* the mathematical relationships, *see* Appendix I (page 85)), and if an infinite number of such planes be taken, a surface of contact will be obtained. The actual amount of the surface of the worm in contact at any moment is the curved line of intersection of its own surface and the surface of contact. The representation of the surface of contact on a plane can be accomplished by drawing a number of lines of contact by various parallel planes in juxtaposition.

In Fig. 19 (page 72) the lines of contact are drawn for a worm whose acting face is generated by the line *aa*, which rotates and advances along the axis at the rate of 18 inches for one complete turn. The pitch plane is situated 3 inches from the axis and the inclination of *aa* to the axis is 15°. The surface generated therefore is that of a right-hand worm whose pitch is three times the pitch diameter. The lines *bb*, *cc*, *dd*, *ee*, *ff*, and *gg*, are sections of the worm surface by planes whose traces are AA, BB, CC, DD, EE, FF, and GG, in the transverse section. The corresponding lines of contact are a_1a_1, b_1b_1, c_1c_1, d_1d_1, e_1e_1, f_1f_1, and g_1g_1, which are the sections of the surface of contact by the planes of section AA, BB, etc. (In this and all other figures giving the surface of contact the sections of the acting face of the worm and the contact paths have been obtained by calculation using the formulæ in Appendix I.) The surface is seen to be twisted. All sections of the contact surface cut the line PP whose trace in the longitudinal section is *p*. It will be seen that there are no real lines of contact corresponding to sections of the worm surface *cc* and *dd* by planes CC and DD. The dotted line d_1d_1 and c_1c_1 represent imaginary contact lines fulfilling the mathematical conditions of contact only, physical contact being prevented by interference. There are real contact paths beyond the regions of the diagram corresponding to the sections *dd* and *cc*, but they are at such a distance to the left of the diagram that in conditions likely to arise in practice they may be ignored.

The contact surface of the Fig. 19 is typical ot the contact surfaces common to all very "steep pitched" worms where the helical angle at the pitch line approaches 45° (the angle in this case being 43° to 50°). Certain peculiarities should be noticed. The useful or effective portion of the contact surface is much more extended transversely, on the side to the left of A A in the transverse section, or behind the central plane in the longitudinal section. On the other hand, the inclination of the contact line on this side is greater as the distance from the central plane is increased. The inclination of g_1g_1 at the commencement of contact is very marked, whilst that of the line b_1b_1 denotes a considerably reduced obliquity. In Fig. 20 (page 73) the scheme of lettering is the same as in Fig. 19, the worm represented in this case being one whose pitch is equal to the pitch diameter, the helical angle being 16° to 42°.

Fig. 20a (page 73) represents the sections of profiles and contact surface of a worm of the same diameter, the pitch being reduced to 2 inches and the helical angle being 6° 4′. The distortion of the contact surface is much less marked, and as the ratio of pitch to pitch diameter (as in Fig. 20a) becomes less and less, the tendency of the surface to coincide with an oblique plane whose trace is a_1a_1 becomes greater and greater.

The limitation of the contact surface to the left of A A is not here so apparent, but the tendency towards greater obliquity on that side of the worm which, as it rotates, is advancing towards the central plane is still marked, though not to the extent indicated in Fig. 19 (page 72). In conjunction with the foregoing remarks, Figs. 19, 20, and 20a, sufficiently indicate the general tendency of the surface of contact for any given worm, but the actual amount of contact depends upon the limitations imposed by interference or by the intersections of the surfaces bounding the two gears with the contact surface.

Fig. 21 (page 74) is drawn to scale to illustrate the actual boundaries of the contact surface in the case of right-hand worm 8 inches diameter, 8 inches pitch (double thread), gearing with a worm-wheel with 30 teeth. The lettering is similar in all three

FIGS. 19 to 20a.

Plane Sections of Contact Surface for various ratios of Pitch to Diameter.

Transverse Sections.

Longitudinal Sections.

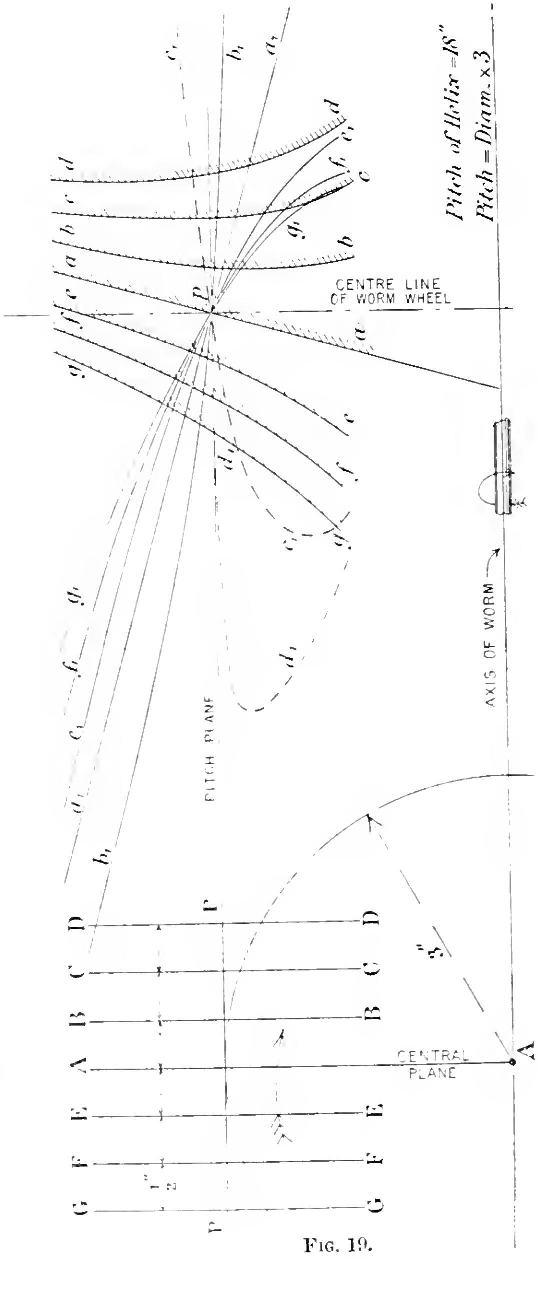


FIG. 19.

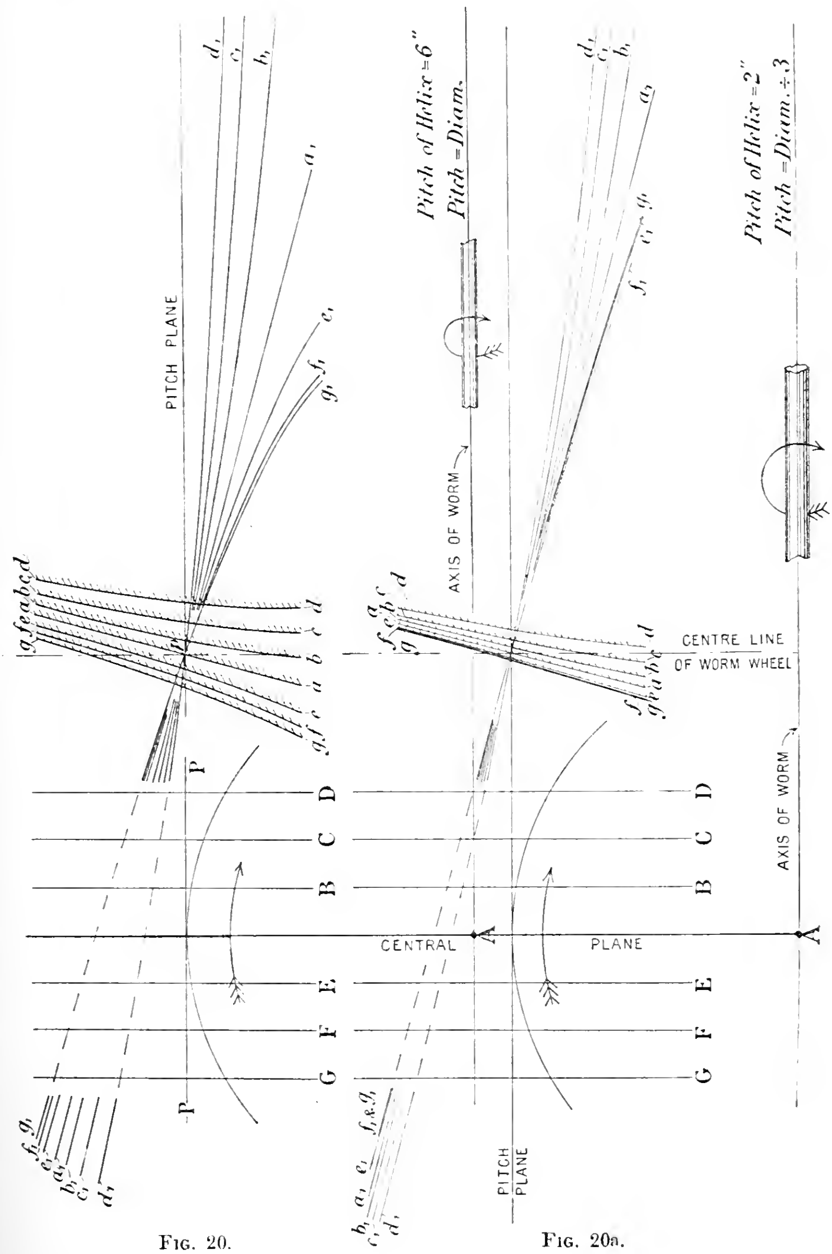


FIG. 20. FIG. 20A.

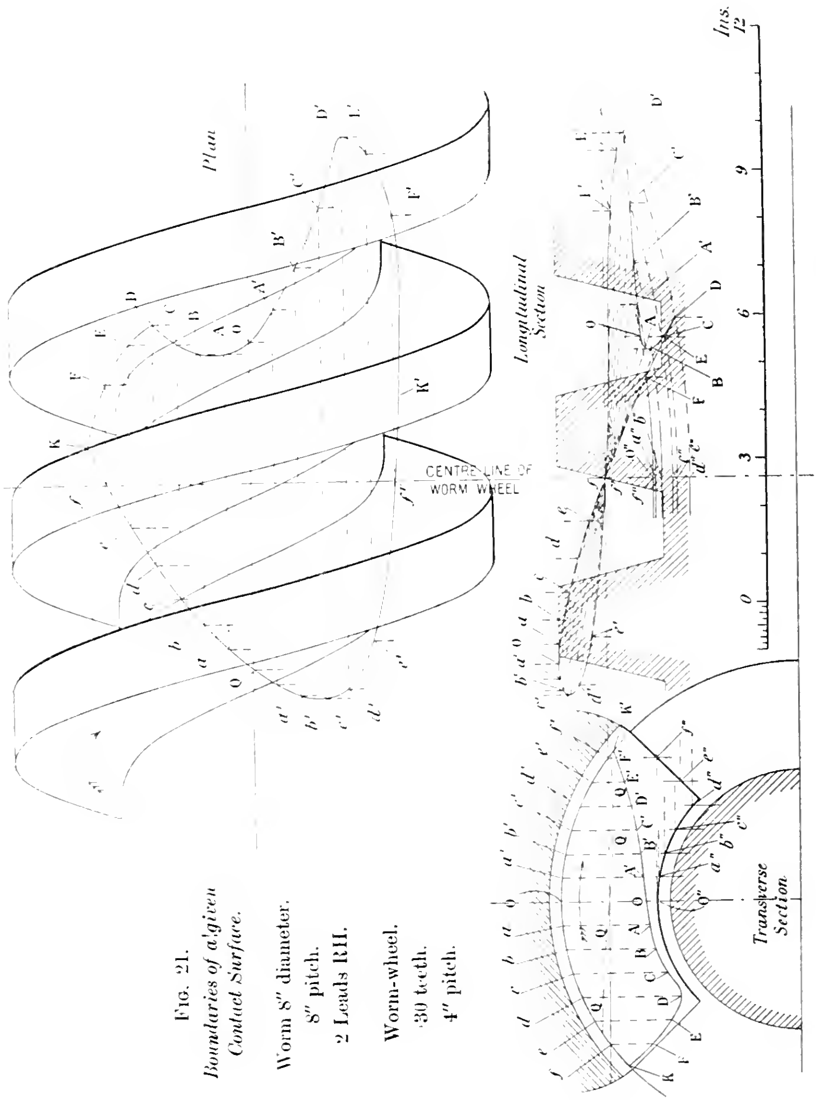


Fig. 21.
Boundaries of a given Contact Surface.

Worm 8" diameter.
8" pitch.
2 Leads RH.

Worm-wheel.
30 teeth.
4" pitch.

views of the contact surface, the boundary of which is KOK^1O—the dotted lines a A, a^1 A^1, etc., represent lines of contact in planes parallel with the central plane (that is, dividing the worm-wheel symmetrically and containing the axis of the worm). It will be readily seen that the lines of contact are much more extended on the side of the contact surface where the worm-wheel teeth are receding from the central plane (that is, on the lower side in plan), and that the average obliquity of contact is at the same time less on that side. It must not, however, be imagined on this account that the receding side of the contact surface is the more valuable, for in determining the ability of the surfaces in contact to transmit pressure without undue wear or abrasion, it is necessary to consider the mutual forms of the surfaces in contact as well as the length over which contact is maintained. The actual contact at any moment takes place along a curved line which is the intersection of two surfaces, namely, the acting surface of the worm and the surface of contact. Thus, in Fig. 21, the line Q Q in the transverse section of the worm shows the line of contact across the face of the worm at the moment when contact takes place at the pitch-point. Mathematically, contact along a line yields no area, but it is scarcely necessary to state that the elasticity of the surfaces and the viscosity of the lubricant in conjunction contribute to expand this ideal line contact into contact over an area on either side of this line.

The relative curvature of the surfaces in contact must therefore be carefully considered, for it is obvious that if they have opposite curvatures, as is the case with surfaces mutually convex, the area of physical contact will be much less than is the case where the curvatures are in the same direction, as happens when a concave touches a convex surface. The influence of the curvature of profiles in contact is illustrated in Figs. 22 and 23 (page 76), which represent various positions of the profiles of the worm and wheel of Fig. 21 (page 74), the planes of section being symmetrically chosen with reference to the central plane. The contact along dD in Fig. 22, though much less extended than that along d^1D^1 in Fig. 23, is of a kind much more adapted to withstand heavy pressures, the convex profile of the worm-wheel fitting into the concave profile of the worm in

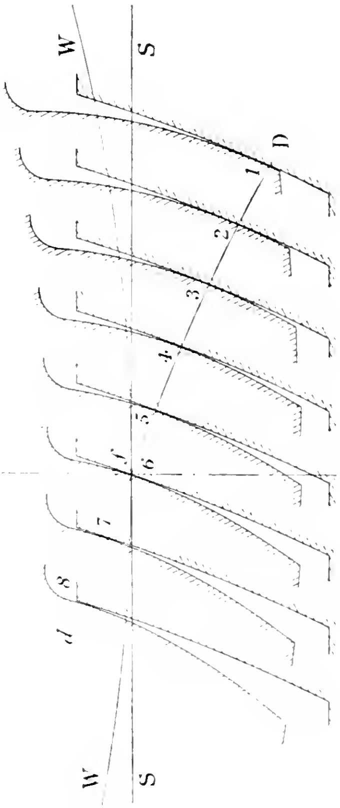


Fig. 22.—*Sections of worm and worm-wheel Teeth in contact by plane d D on advancing side of worm.*

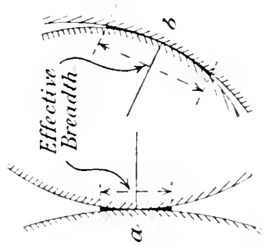


Fig. 24.—*Influence of Curvature on Effective Breadth of Contact Film.*

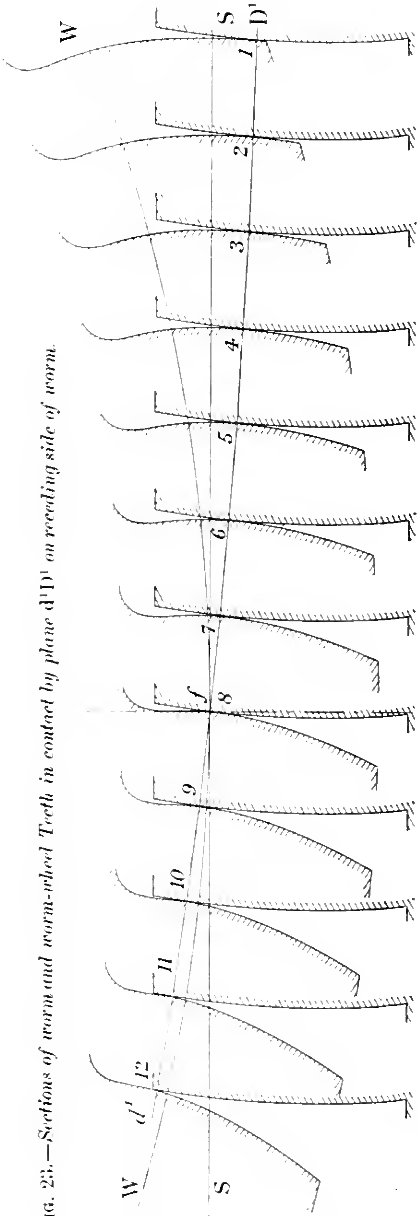


Fig. 23.—*Sections of worm and worm-wheel Teeth in contact by plane d'D' on receding side of worm.*

Fig. 22, whereas in Fig. 23 the opposite curvatures of the profile are less suited for retaining the oil-film upon which the power of sustaining a load depends. Generally speaking, on the side of the central plane where the worm is advancing the curvature of the profiles is alike, though the path of contact is less extended, whilst on the side of the central plane where the worm is receding the contact path is more extended, and the curvature of the profiles is unlike. It follows, therefore, that the mere extension of the contact surface of a worm and worm-wheel is insufficient in itself to determine the amount of end pressure which can be safely sustained at any given speed, the curvatures of the various sections of the surfaces in contact playing an important part. The ability of any given worm-gear to withstand wear depends upon the maintenance of an oil or grease-film between the surfaces in contact. As the tooth of a worm-wheel passes through all the phases of its contact with the worm-thread, the line of contact traverses across its face, and is therefore continually passing across portions of the worm which, since being in contact with the preceding worm-wheel tooth, should, in a well-lubricated system, have been freshly lubricated. The rate of transference of the line of contact over the tooth-face in conjunction with the tangential rubbing velocity is therefore a factor of prime importance. The width of the contact line or its dimensions across the face of the teeth and its effective breadth are factors of equal importance. By "effective breadth" the dimension parallel to planes of section is meant, *see* Fig. 24 (page 76). The "effective breadth" is indeterminable, but a comparative estimate can be formed of it by considering the curvature of the surfaces at any section. Thus, in Fig. 24 (page 76), it is obvious that a much greater load would be sustained by a surface such as is illustrated at a than by surfaces such as b. In Appendix II (page 88) reasons are given for taking the quantity $K\sqrt{\frac{r_1 r_2}{r_1 \pm r_2}}$ as a measure of the effective breadth, where r_1 and r_2 are the radii of curvature of the surfaces at the point of contact. According to this view the effective breadth is proportional to the square root of the product of the radii divided by the square root of their sum or

difference, according as the curvatures are opposite or alike. In Appendix III (page 89) an expression is given for this measure of the effective breadth when contact occurs at the pitch-plane, and it is sufficiently near the truth to take this value as an average value for any particular section. A Table has been prepared (*see* Appendix IV, page 91) giving the values for the "effective breadth," of the sections of Figs. 19, 20 and 20a (pages 72 and 73). Broadly speaking, the result of the calculations summarised in Appendix IV is that, for worm-wheel drives of similar general proportions as to height of teeth and arc of worm embraced by the worm-wheel (in transverse section), the average "effective breadth" of the contact line varies very slightly, on account of variations in the ratio of thread-pitch to diameter of worm. On the other hand, the effect of increase in diameter of the worm-wheel has a markedly beneficial effect in this respect, the effective breadth varying as the square root of the diameter of the worm-wheel. The average width of the contact line across the face of the teeth will vary directly as the diameter of the worm, the slight diminution in width when the ratio of thread-pitch to diameter is high being nearly balanced by the tendency towards greater "effective breadth."

Therefore, to sum up, the area of physical contact varies as the pitch diameter of the worm multiplied by the square root of the diameter of the wheel; or, if the effects of varying the angle subtended by the pitch-line of the worm-wheel at the centre of the worm be considered, it may be said that the effective area of contact varies as the continued product of the diameter of the worm, the tangent of half the angle subtended by the worm-wheel, and the square root of the diameter of the worm-wheel. At any instant the end pressure is shared between several teeth, and it is therefore justifiable to expect a greater power of sustaining loads as the number of teeth in action is greater. The variation in the number of teeth in gear is, however, much more apparent than real. Except in the case of abnormally small worm-wheels, the length of the contact paths on the worm-wheel side of the pitch-plane is unaffected by the size of the worm-wheel. On the other side, the contact lines most affected are those which are flattest, or which most nearly

coincide with the pitch-line. The actual variation in the number of teeth in gear at any one time is found on careful investigation to be small for widely differing sizes of worm-wheel. So that in comparison with other more important matters it may be neglected (*see* Appendix V, page 92).

By keeping the ratio of the height to the thickness of the teeth as large as practicable, the greatest possible number of teeth are enabled to operate simultaneously, but at the same time, in order to avoid interference, the teeth should be pitched as finely as is compatible with strength and allowance for wear. It should be noticed that in respect of the height of the teeth the dictum given above is in direct opposition to the best practice with spur-gearing, where entirely different conditions are in force.

The effect of the angle of the worm-thread remains for consideration. As the ratio of pitch to the diameter of worm becomes greater, the thrust of the worm is borne on a surface of greater inclination and the actual pressure on the teeth is increased in the same ratio as the secant of the angular pitch. At the same time the width of the contact line across the face of the teeth is increased in the same ratio, so that the actual pressure per unit of width remains the same. It is not necessary therefore to take any account of the angle of the helix in making estimates of the "effective contact area." Under precisely similar conditions as to temperature, lubrication, nature of the surfaces in contact and rubbing velocities, it might reasonably be anticipated that the end thrust would be proportional to the effective area, and neglecting comparatively unimportant factors the relation may be expressed as follows:—

$$P = K \cdot \sqrt{D} \cdot d \tan \frac{\beta}{2}$$

= some factor depending on conditions × effective breadth × effective width across the face of the worm-teeth.

where P = safe end-pressure in lbs.

d = diameter of worm at pitch-line.

D = diameter of worm-wheel pitch-line.

β = angle subtended by the worm-wheel at the axis of the worm.

K = a factor depending upon rubbing velocity, nature of the surfaces, temperature and nature of the lubricant, etc.

Experience has shown that this relationship is far from simple in practice, because of the great difference in the factor K imposed by variable conditions. Broadly speaking, what happens in the case of a worm-wheel drive is very much what happens in the case of a loaded journal. The action commences under certain conditions as to speed, temperature and so forth, and as it proceeds heat is generated owing to frictional resistance, the amount depending upon the load, the lubricant and the efficiency of the gear. The temperature of the system rises until the heat generated by friction balances the heat lost by radiation and convection, when a stable set of conditions is established. But whilst the temperature is rising, the lubricant is losing its viscosity, and, though this tends to diminish the friction and consequently the generation of heat, it nevertheless diminishes the power of sustaining a heavy load. A worm will therefore be successful if the viscosity of the lubricant does not diminish to such an extent that its load-sustaining properties are neutralised. If the surfaces be allowed to come into grinding contact, further heating takes place, and the lubricant becomes still less viscous and therefore incapable of bearing a load, and seizing will take place quickly.

The question as to how much of the work done in rotating the worm is converted by friction into heat, can only be answered when the pressure, the velocity, the angular pitch, and the coefficient of friction between the surfaces, are all known.

Thus L = Lost work per minute $= Pv\mu \left\{\frac{1 + a^2}{1 - a\mu}\right\}$ (*See* Table 2, page 84.)

where P = end thrust in lbs.

v = circumferential velocity of worm at pitch-line in feet per minute.

a = tangent of angle of thread (θ).

μ = coefficient of friction.

The useful work performed in the same time is U where $U = Pva$.

So that the proportion of lost to useful work is expressed thus:

$$\frac{L}{U} = \frac{\mu}{a} \left\{ \frac{1 + a^2}{1 - a\mu} \right\}$$

A diagram is given, Fig. 25 (page 82), showing the values of the fraction $\frac{L}{U}$, for various values of μ and θ. The values to be ascribed to μ are somewhat difficult to arrive at. In experiments by Bach and Roser on a soft steel worm meshing with a bronze worm-wheel lubricated copiously with a heavy cylinder-oil, μ calculated from the ratio of L to U varied from 0·067 to 0·027, being generally speaking highest at low velocities (50 feet per minute) or at high velocities (over 1000 feet per minute); whilst at medium velocities (270–550 feet per minute) it was lowest, varying little (0·037 to 0·027) under widely differing loads. In some experiments made by Messrs. Sellers and Co. on cast-iron surfaces the coefficient was highest at very low velocities (3 feet per minute), and gradually got less as the velocity increased up to 200 feet per minute. The variations of the coefficient are shown in the following Table 1.

TABLE 1.

v = rubbing velocity in feet per minute (reckoned as circumferential velocity of worm at pitch diameter).

μ = coefficient of friction, cast-iron on cast-iron, lubricated with lard oil.

RUBBING VELOCITY = v.	COEFFICIENT OF FRICTION = μ.
3	0·086
5	0·078
10	0·064
20	0·050
50	0·035
100	0·025
200	0·018

In these experiments the value of μ varied but little for varying values of pressure. Values of μ deduced from Bach and Roser's experiments are given in the accompanying diagram, Fig. 26 (page 83).

The advantage of employing worms with as large a thread angle as possible, that is to say, with the greatest possible ratio of pitch to diameter, now becomes apparent.

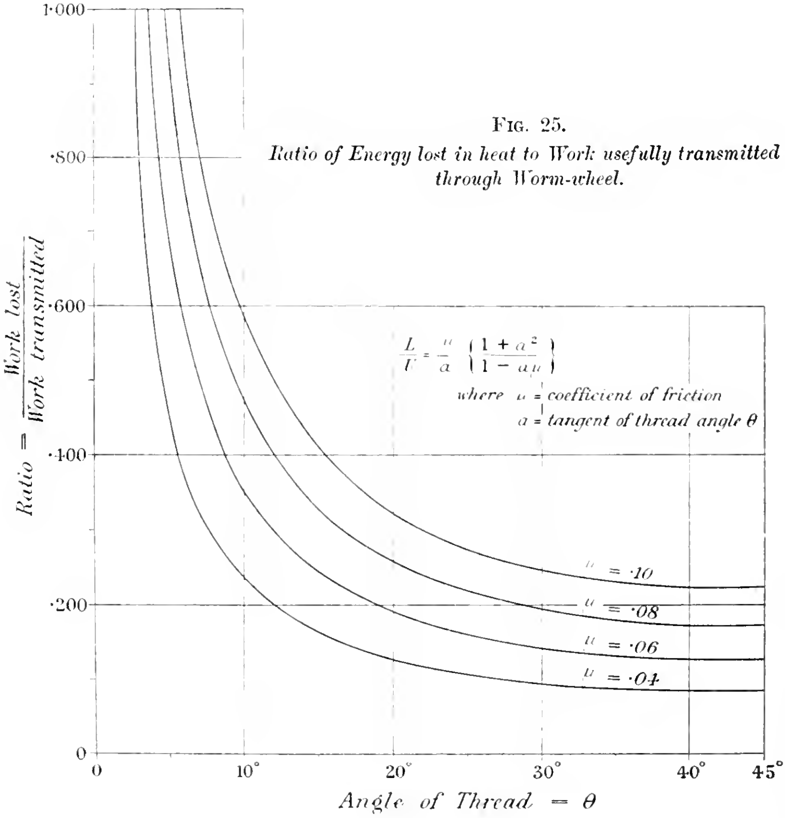
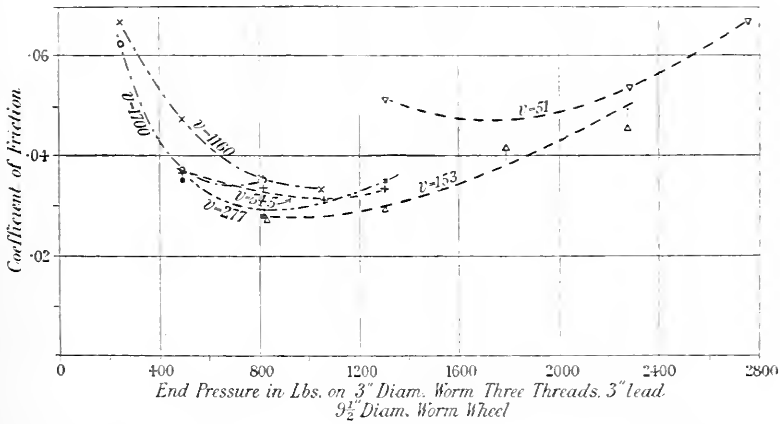


FIG. 25.
Ratio of Energy lost in heat to Work usefully transmitted through Worm-wheel.

For a given amount of work to be performed, by doubling the pitch the velocity is halved and the work wasted in heat is materially reduced. The effect is twofold: the temperature of the lubricant being less, its viscosity is sustained; and the velocity being less,

the value of the load that may safely be borne is increased. Such experiments as have been made to determine the relationship between the pressure and velocity are not altogether concordant, and it remains to establish firmly the laws which govern this sort of friction. The most careful experiments known to the author were those on a soft steel worm-gearing, with a bronze worm-wheel, with oil-bath lubrication, made by C. Bach and Roser, already alluded to. The lubricant was a very thick cylinder-oil, and the experiments were continued till there was no further rise of temperature, the heat lost through radiation balancing the amount generated in friction.

FIG. 26.—*Relation between Coefficient of Friction, Pressure, and Velocity.*
(Deduced from Experiments of Bach and Roser.)
v = Velocity in feet per minute.



The values of K in the appended Table have been calculated from the experiments. If the values of P are calculated by means of the values of K here given, it must not be assumed that they are the highest values that can be safely adopted, but they represent the pressures which may be adopted for continuous running with limited rise in temperature. It must be pointed out, however, that they are only reliable if the conditions of the original experiments are carried out. These were as follows: the lubricant used was a viscous cylinder-oil and the surfaces soft steel and bronze, the worm dipped into an oil-box whose volume was about three times

that of the worm, and the worm-wheel was enclosed. It will readily be seen, therefore, that with superior methods of cooling and by the choice of superior working surfaces, very much larger working pressures might be realised, especially if the worm be of hardened steel.

TABLE 2.

Values of K in formula $P = K \sqrt{D.d} \tan \frac{\beta}{2}$ deduced from the experiments of Bach and Roser. The conditions being:—

Material.—Soft steel worm. Bronze worm-wheel.

Lubricant.—Heavy cylinder-oil.

Lubrication.—Worm dipping in oil bath. Size of bath about three times volume of worm with proportionate cooling surface.

Values of K.

Rubbing Velocity. Feet per Minute.	Limit to Rise of Temperature.		
	50° F.	75° F.	100° F.
100	111	151	182
200	81	112	144
300	62	92	121
400	48	77	107
600	29	57	85
800	15	43	71
1,000	4·6	32	60
1,200	—	25	52
1,400	—	18	46

The experiments of Messrs. Sellers already alluded to showed that for short periods the value of K for velocities up to 200 feet per minute might be as high as 320 in the case of cast-iron surfaces lubricated with lard oil. For continuous running, however, much lower values should be taken.

The Paper is illustrated by 26 Figs. in the letterpress and is accompanied by 5 Appendices.

APPENDIX I.

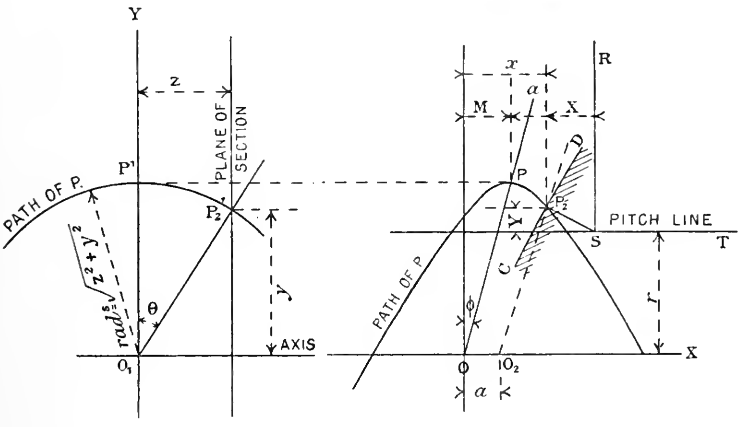
Let OX, Fig. 27, represent the axis of a screw or worm, and OP the generator of one of its acting surfaces, both being in the vertical plane.

The intersection of OP and the axis OX at O is chosen as the origin of co-ordinates.

The worm surface is generated by the generator simultaneously advancing along and rotating about the axis OX; an advance of p units corresponds to one complete revolution.

FIG. 27.

End Elevation. *Side Elevation.*



Let a be the advance of the generator along OX when the latter is turned through an angle θ.

$$\text{Then } a = \frac{p\theta}{2\pi} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

When the generator rotates through an angle θ it moves from the position OP to O_2P_2 (*see* side elevation, Fig. 27) or from O_1P^1 to $O_1P'_2$ (*see* end elevation).

Then it is easily seen from the figure that

$$\sin \theta = z\,(y^2 + z^2)^{-\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Hence
$$a = \frac{p}{2\pi} \sin^{-1} z\,(y^2 + z^2)^{-\frac{1}{2}} \quad . \quad . \quad . \quad . \quad (3)$$

$$M = (z^2 + y^2)^{\frac{1}{2}} \tan \phi \quad . \quad . \quad . \quad . \quad (4)$$

and $x = M + a = (z^2 + y^2)^{\frac{1}{2}} \tan \phi + \frac{p}{2\pi} \sin^{-1} z\,(y^2 + z^2)^{-\frac{1}{2}}$. (5)

The expression (5) is the equation of the generated helical surface.

In order to obtain the equation of the curve of intersection of such a surface by a plane parallel to the axis and distant d from it and from the initial position OP of the generator, one has only to put $z = d$ in (5) and the following equation is obtained :—

$$x = A\,(d^2 + y^2)^{\frac{1}{2}} + B \sin^{-1} d\,(y^2 + z^2)^{-\frac{1}{2}}. \quad . \quad . \quad (6)$$

Differentiating

$$\dot{x} = Ay\,(d^2 + y^2)^{-\frac{1}{2}} - Bd\,(y^2 + d^2)^{-1} \quad . \quad . \quad . \quad (7)$$

Differentiating again

$$\ddot{x} = Ad^2\,(d^2 + y^2)^{-\frac{3}{2}} + 2Byd\,(y^2 + d^2)^{-2} \quad . \quad . \quad (8)$$

where A, d and B are constants.

The radius of curvature at any point xy is

$$e = \frac{(1 + \dot{x}^2)^{\frac{3}{2}}}{\ddot{x}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Again, $\dot{x}$ is the co-tangent of the angle included between the axis and the tangent to the curve of section at the point whose co-ordinates are xy. Or again, $\dot{x}$ is the tangent of the angle included between the normal to the curve of section at xy and the pitch-line (which is parallel to the axis).

In Fig. 27 (page 85) CP_2D is the plane section of the helix and P_2S is the normal at P_2. S is therefore the pitch-point, and if RST are fresh axes of co-ordinates, and X and Y the co-ordinates of P_2 referred to them, then

$$Y = X\dot{x} \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

which is the equation of the path of contact belonging to the plane section whose equation is (6).

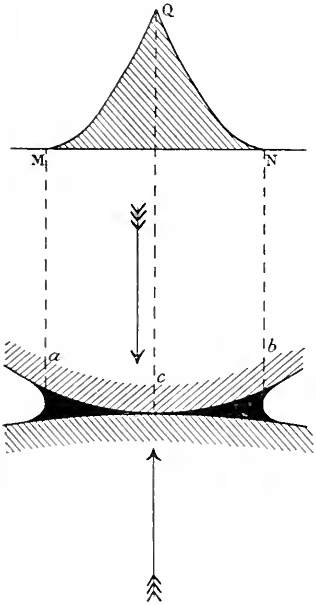
In using (10) it must be remembered that

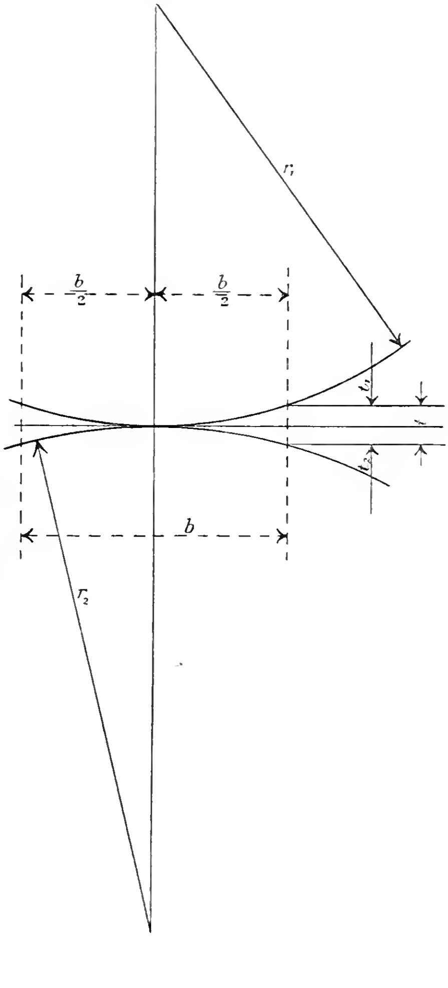
$$y = Y + r \qquad . \quad . \quad . \quad . \quad . \quad (11)$$

where $r =$ the pitch radius of the worm. And hence (10) can be expressed in terms of X and Y and constants.

FIG. 28. FIG. 29.

Lubricated Curved Surfaces in Contact.





APPENDIX II.

If Fig. 28 (page 87) represents a plane section of the curved surfaces of a worm and worm-wheel, with a thin film of oil or grease sustaining the load pressing them together, it is reasonable to suppose that the intensity of pressure will be greatest at c where they are nearest together, and that it will tend to become zero at points a and b, where the surfaces are so separated that the oil-film breaks down. The distribution of pressure may in fact be represented by the curve MQN, ordinates from the base line MN representing intensity of pressure. The width MN may be taken as representing the "effective breadth" of contact for the section. It is clear that this "effective breadth" varies with the curvature of the surfaces, the nature of the lubricant and the surfaces themselves, and the relative or rubbing velocity. Whilst the effect of the last three of the variables enumerated can be only dealt with experimentally, the effect of curvature alone can be treated mathematically. Thus for constant conditions of lubricant, nature of surfaces and rubbing velocity, there should be some thickness of film t at which the power of sustaining load becomes nil. This thickness t may be considered constant under the conditions laid down.

Let the radii of curvature of the surfaces where their distance apart is least (*i.e.* where the oil-film is infinitely thin) be r_1 and r_2; then, since films of capillary thickness are being dealt with, the dimensions in this direction may be treated as infinitesimals compared with r_1 and r_2.

The following equations may be verified from Fig. 29 (page 87).

$$\left(\frac{b}{2}\right)^2 = t_1\,(2r_1 - t_1) \qquad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$\left(\frac{b}{2}\right)^2 = t_2\,(2r_2 - t_2) \qquad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Hence since t_1 and t_2 are small compared with r_1 and r_2

$$b^2 = 8r_1t_1 \qquad \ldots \qquad (3)$$

$$b^2 = 8r_2t_2 \qquad \ldots \qquad (4)$$

Hence $t = t_1 + t_2 = \frac{b^2}{8}\left(\frac{1}{r_1} + \frac{1}{r_2}\right) \qquad \ldots \qquad (5)$

or

$$b = \sqrt{t} \times \sqrt{\frac{8r_1r_2}{r_1 \pm r_2}} \qquad \ldots \qquad (6)$$

The negative sign indicating similar and the + sign indicating dissimilar curvatures.

But as t is supposed constant for the assumed constant conditions of speed, lubrication and surfaces, one may write

$$b = K\sqrt{\frac{r_1r_2}{r_1 \pm r_2}} \qquad \ldots \qquad (7)$$

In this investigation the surfaces are supposed to be actually touching at one point, a condition not quite in accordance with what one might anticipate, but it may reasonably be assumed that the film's thickness at the minimum distance of the surfaces is small compared with its maximum thickness, so that equation (7) may be regarded as approximately true.

APPENDIX III.

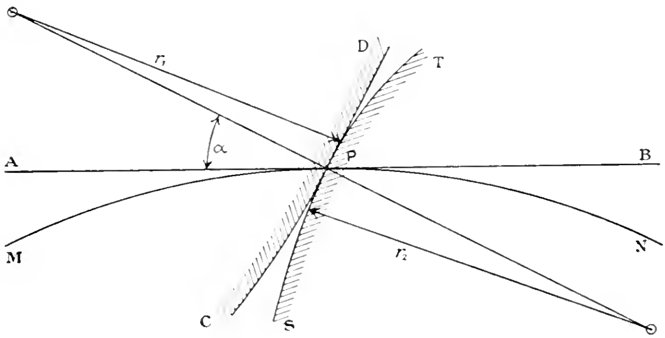
The expression given for the effective breadth of contact is capable of considerable simplification when contact takes place at the pitch-line.

The theorem upon which this depends is to be found in any work which treats of the curvature of the envelope of a curve carried by a rolling curve and invariably connected with it, and is attributed to Chasles (*see* "Williamson's Differential Calculus," 6th edition, page 355).

Let AB, Fig. 30, be a straight line (the pitch-line of a worm), and CD a curve connected by it and carried by it (a worm-tooth section). Let AB roll on the circle MN (the pitch-line of the worm-wheel), and in so doing let CD generate the envelope ST (which is therefore the section of the mating worm-wheel tooth). Then, when contact

FIG. 30.

Curved Surfaces in Contact.



takes place at the pitch-line, if r_1 and r_2 are the radii of curvature of the surface sections in contact at P—

$$\frac{r_1 r_2}{r_1 + r_2} = R \cos \alpha,$$

where R is the radius of MN (and therefore the pitch-line radius of the worm-wheel), and α is the angle of inclination of the contact path at the pitch-line.

Hence at the pitch-line $b = K\sqrt{R \cos \alpha}$. This expression for $\frac{r_1 r_2}{r_1 + r_2}$ is a good average value for the contact of any two sections of worm and worm-wheel throughout their contact.

APPENDIX IV.

It has been already shown that

$$b = K\sqrt{R \cos a}$$

The Table given below shows that the average value for $\sqrt{\cos a}$ does not greatly alter for very considerable variations of the ratio of worm-thread angle. The pitch radius of the worm is throughout 6 inches.

Refer to Figs. 19, 20, and 20a (pages 72–73).

TABLE 3.

Section on Plane Lettered.	Z = Distance of Section from Central Plane.	Values of $\sqrt{\cos a}$			
		Pitch = 2 ins. See Fig. 20a of Text.	Pitch = 6 ins. See Fig. 20 of Text.	Pitch = 12 ins. Not Illustrated.	Pitch = 18 ins. See Fig. 19 of Text.
	Ins.				
DD	1·5	0·440	0·338	No Contact.	No Contact.
CC	1·0	0·454	0·394	0·252	No Contact.
BB	0·5	0·488	0·455	0·399	0·329
AA	0·0	0·508	0·508	0·508	0·508
EE	−0·5	0·520	0·550	0·587	0·621
FF	−1·0	0·522	0·573	0·638	0·690
GG	−1·5	0·523	0·588	0·665	0·725
Average Value . .		0·49	0·48	0·43	0·41

APPENDIX V.

In the case of an ordinary worm with straight-sided teeth whose sides are inclined to each other at an angle of 29°. The average number of teeth in contact from the moment when contact takes place till the pitch-line is reached can be found from the equation—

$$N = 0 \cdot 258\, n \pm \sqrt{0 \cdot 108 + 0 \cdot 667\, n + 0 \cdot 0667\, n^2}.$$

Where n = ratio of worm-wheel radius to pitch of the teeth.

If $n = 2$ the wheel has 12 teeth and $N = 0 \cdot 75$
$n = 10$ „ „ „ 63 „ „ $N = 1 \cdot 09$
$n = 100$ „ „ „ 628 „ „ $N = 1 \cdot 3$

As the number of teeth engaged between the pitch-line and the point where contact ceases is unaffected by n, the total number of contact surfaces in action in any given gear is but slightly affected by the number of teeth in the wheel.

Discussion.

Mr. C. G. Major said the subject of the Paper was one in which he was exceedingly interested, because during recent years he had had some little experience in connection with it. He thought the Institution owed a debt of gratitude to the author for writing a Paper upon a subject which had, he believed, but little literature devoted to it. As the author had remarked, the subject was very much unknown and the field unworked. Those who had to deal with the subject practically worked in the dark, and had to feel their way, so to speak. His prominent feeling with regard to the Paper was one of regret that the author had not been able to go further with it, and that he had not been able to go still further and give some practical and quantitative results. So far as he had gone, it appeared to him he had treated it in a very masterly manner. Incidentally the author had referred to the possibilities of improving

apparatus by using hard steel worms. The intention he probably had in mind, as throughout the whole of the Paper, was the elimination of wear and tear.

The keynote of the Paper was the increase of effective contact surface, the object being to get a larger area of lubrication, preventing the surfaces coming into contact, so that they could not tear and wear. It appeared to him that the author departed from that theory when he suggested that different combinations of metal would improve the conditions. That would depend, of course, upon what was meant by improving conditions. If simply the elimination of the tendency to tear, to seize and so destroy surfaces was meant, then no doubt hardening the texture of one metal, or using a combination of it with one of different texture, would prevent the tendency to seizing, but it would not prevent the wear. That would remain just the same: the softer metal would suffer, and the harder metal would maintain its dimensions. In nearly every case where worm-gear had to be used, wear and tear were very detrimental to the results aimed at in the machine, and it was not much use getting rid of seizing and tearing if at the same time the slow process of wear was allowed to proceed. It appeared to him that it was necessary to go to the root of the matter, and get rid of the element which led to wear and tear; in other words, to increase the effective lubricating surfaces—the effective surface of contact.

Probably the difficulties engineers had to encounter in dealing with the subject had arisen from an attempt to design a worm-gear on the same lines as spur-gear. Spur-gear had been mostly designed from the point of view of strength, and abrasion entered into the problem to a very small extent. Taking a spur-gear, say $1\frac{1}{2}$ inch pitch, the movement of one given point on any tooth upon its neighbour would probably be, from the moment of entry to the moment of exit, not more than $\frac{1}{8}$ inch. That was the abrasive moment. There would also be a rolling contact and a rolling movement, but the two surfaces would probably not slide upon each other more than $\frac{1}{8}$ inch. But, taking a worm and worm-wheel of the same pitch and of the ordinary proportions which would be used in practice, the chances were that there would be an abrasive

(Mr. C. G. Major.)

movement of 3 feet. It was very obvious that the wear and tear in one case would be enormous as compared with the other, and a different set of conditions had to be faced. What would answer with spur-gear would not answer with worm-gear. Consequently, worm-gears designed on the basis of spur-gears had been made very much too small and had cut. Then an attempt had been made to stop the cutting, and combinations of metals had been introduced, phosphor-bronze and gun-metal, in either one element or the other, with a harder metal as the complement. The result had been that the wear occurred just the same, but not the seizing. Instead of doing that, what was wanted was to increase the surfaces right through, so that the oil never squeezed out. Paraphrasing an old saying, if one took care of the surfaces the metals would take care of themselves. If the size of the wheels and the worm-surfaces were enlarged beyond those usually employed, then probably they would be able to use practically any pair of metals and work without difficulty. During the last six years he had had an opportunity of experimenting with some 300 or 400 sets of worm-gears of various sizes, with very heavy pressures, and careful and close observation showed that the results had all tended in that direction. If actual contact was got rid of, it did not much matter what metal was used.

Mr. J. HARTLEY WICKSTEED, Past-President, said the last speaker had stated that he wished examples had been brought forward showing that the theory advocated by the author had been actually put into practice. He thought sufficient examples had been made in his own Works (Messrs. Buckton and Co., of Leeds), of which the author of the Paper was Manager, to say at any rate that the theory was sound. In one instance a worm-gear had been made where the pressure upon the teeth was 25 tons, and where the velocity of the worm-thread to which Mr. Major had referred was 120 feet per minute. The lubrication and the shape of the teeth had been attended to, and the results confirmed the theory, because he thought all present would agree that a pressure of 25 tons was a very severe test.

Another instance of practice that came before him was that of a worm-wheel which was driving a slotting ram that would take off a shaving an inch deep of $\frac{1}{16}$-inch feed, which was not enough for the purpose for which the machine was intended. It was intended to cut down very rough forgings, and shape them into the checks of built-up marine cranks, which were a sort of double curve a figure 8. In some cases there were 3 inches of material to be removed. The same diameter of worm-wheel, the same diameter of worm, and the same multiplying power between the two were put together again with a more scientifically formed thread, and the machine then, instead of cutting 1 inch deep with $\frac{1}{16}$-inch feed, cut 3 inches deep with $\frac{1}{16}$-inch feed. He was very glad that the Institution appreciated the points that had been brought forward by the author. It seemed to him clear that, in the first instance, the author had established the fact that a line contact could be obtained, which was not a contact of two points, but of two lines, that the curves could then be made in the same direction, and thereby spread out the possible surface contact, when an allowance had been made for the compression of the metal at the points of contact, and for the viscosity of the oil.

Mr. BRUCE, in reply, thanked the members for the kind way in which the Paper had been received. He had hesitated for some time in bringing it forward, because he felt that he would be very much exposed to criticism in reading a Paper on what might be called theory, based on supposition, without adducing fresh evidence in confirmation of those views. The fact of the matter was, however, that experiments of anything like the scope which would be needed to substantiate the Paper and do any real good were beyond the reach of any but a wealthy experimenter, or one with a great deal of leisure, because two or three experiments and a few isolated results would not suffice. There was no doubt whatever that worms and worm-wheels were now becoming a very highly favoured means of power transmission; and he desired to raise the definite query whether, in view of the growing use of worms and worm-wheels, it was not worth while some learned society taking the matter up, either by means of a Committee or by some other method of that

(Mr. Bruce.)

kind. Experiments of the requisite scope were beyond the means of an individual. He merely threw that out as a suggestion.

There was one point made by Mr. Major to which he should like to reply. He felt with Mr. Major that it was irrelevant to a certain extent to talk about the nature of the metal, when he had been laying so much stress upon the question of contact surfaces. If the surface were properly lubricated, it was obvious that the nature of a metal ought to have very little to do with the subject. If it were a real case of lubrication, it was a case of fluid friction and not metallic friction. However perfect the lubrication was, and however perfectly designed the opposed surfaces were, a time would surely come when the lubrication, even of one particular tooth, was not quite so perfect as it should be. Some accidental failure would take place; some grit would work into the mechanism, and in that case the nature of the material was all-important, because it was just such a little rift within the lute which unchecked might cause serious mischief. If abrasive action were once set up, heating would result, the liquid would lose its viscosity, and the seizing action to which he had referred in the Paper would commence. He therefore attributed the very greatest importance to the worm being hardened. Although he said that the worm should be hardened, theoretically the worm-wheel might be hardened and the worm might be soft; but he thought it was obviously correct that the worm should be hardened and the worm-wheel soft, because, in the first place, it was more easily accomplished, and, in the next place, that portion which received the most wear should naturally be the most resisting.

The President said it was evident from the applause with which the Paper had been greeted that the author had won the hearty vote of thanks that his Paper deserved; but to put himself in order he formally proposed a hearty vote of thanks to Mr. Bruce for his most interesting Paper.

The resolution was carried by acclamation.

Communications.

Mr. N. L. PROSSER wrote asking for information regarding the peripheral velocity of worms. He noticed, on reading the Paper, that the highest rubbing velocity mentioned was 1,400 feet per minute. With the Parsons steam-turbine, however, he had data of peripheral velocities varying between 1,800 and 4,000 feet per minute. Taking an actual case of a mild-steel worm, 4·625 inches pitch-circle diameter, $\frac{7}{8}$-inch pitch, $1\frac{3}{4}$ inches lead, running at 3,000 revolutions per minute, gearing with a bronze worm-wheel $7\frac{7}{8}$ inches pitch diameter, 28 teeth $\frac{7}{8}$-inch pitch and $1\frac{3}{4}$ inches wide on pitch circle, the lubrication of the wheel was effected by the rim being flooded with oil, the latter being of a much lighter nature than that used in the tests mentioned in Table 2 (page 84). The writer would be glad if the author would give some information regarding the maximum peripheral velocity practicable when the work transmitted by the gear was light, say one H.P., such as driving a main governor and oil pump in the case of a turbine; also whether there were any figures regarding the coefficient of friction for steel on bronze at velocities up to 70 feet per second under the above conditions of lubrication.

Mr. H. SPILLMANN, Chief Engineer of the Maschinenfabrik Oerlikon, of Oerlikon, Switzerland, wrote that this firm was one of those which first advocated the use of worm-gearing for transmission purposes under certain conditions. Their early worm-gears were designed only for intermittent service. Even as early as 1892 they based their calculation regarding the efficiency of their worm-gears on the following formula:—

$$\frac{\tan a}{\tan (a + \phi)}$$

where a is the angle of inclination and $\tan \phi$ the coefficient of friction. From this formula it might be concluded at first sight that the efficiency was altogether independent of the power transmitted, since neither the speed nor the pressure between the teeth entered into the formula. But, as a matter of fact, these factors

(Mr. H. Spillmann.)
had an indirect influence on the efficiency, for the coefficient of friction increased with the load and diminished to a certain extent with increasing speed. This formula for calculating theoretically the efficiency of worm-gearing was particularly simple and handy, if the different factors, such as suitable form of teeth, the stress on them, influence of sliding speed, quality of material used, lubrication, etc., had been previously established by actual tests.

The first scientific tests had been carried out by Professor A. Stodola of the Polytechnic at Zürich in 1895 with a double thread worm-gear. It was ascertained that, according to the speed and the power transmitted, the efficiency could work out as high as 87 per cent. The results of this test were published in the Schweizerische Bauzeitung of 1895. This success, which surpassed all expectation, was of course an encouragement to the Maschinenfabrik Oerlikon to investigate more deeply the best conditions for working of worm-gear and for perfecting its manufacture in every possible way. Thus the corrugated bearings were replaced by ball bearings. In order to secure the best materials available numerous trials were carried on. All these efforts had made it possible for the Oerlikon worm-gears to yield such excellent results as they really had done. Whilst efficiencies of 90 per cent. were quite common, it had been proved that under favourable conditions their worm-gears would even yield an efficiency of 93 to 94 per cent. In order to give such high efficiencies, a worm-gear must be designed, manufactured, and run under the following conditions:—

(1) The particular conditions of service must be known to the designer in every case.

(2) The form of the teeth must be as good as possible and the teeth to be worked as accurately as possible.

(3) Full care must be taken in choosing the material.

(4) The lubrication must be excellent.

(5) The construction of the worm-gear as a whole must be extremely careful and accurate in character.

(6) The erection of the worm-gear at the site where it has to work must be given especial care, and should be done under close supervision.

Neglect of one or other of these rules would soon hamper the service of the gear and be the source of continued annoyance both to the client and the manufacturer. The number of worm-gearings supplied by his firm exceeded 3,000. They varied in capacity from small loads up to 75 H.P. and ratios of transmission up to 1 : 56, both for intermittent and continued service. The following Table showed the variety of worm-gearings as manufactured by the Maschinenfabrik Oerlikon during recent years :—

TABLE 4.

Delivery Date.	Service.	Capacity. HP.	Transmission. Ratio.	Efficiency Per cent.
1899	Street Car . . .	18	1 : 13	
1900	Driving roll-train . .	18	1 : 13	
1901	Driving cold-roll mill .	12	1 : 29	87
1902	Driving rolling-mill . .	75	1 : 15	92
1903	Driving calender . .	15	1 : 31	
1904	Driving fly-press . .	12	1 : 7	
1905	Driving pump . . .	43	1 : 21	94
1905	Lifting apparatus . .	6	1 : 56	87

Mr. Bruce, in reply to Mr. Prosser (page 97), wrote that he had no knowledge throwing light upon the questions raised by him. It was such questions as these that had led him to throw out the suggestion that the time had come for serious experimental investigation of such matters. If the theory of continuous lubrication developed in the Paper were true, the limiting peripheral velocity would be reached when, owing to centrifugal forces, lubrication became inoperative. He would point out however that, even though the peripheral velocity of the worm was such that the lubricant was flung off centrifugally, the velocity of the worm-wheel might be so much less that sufficient lubrication between the teeth might still be

(Mr. Bruce.)

possible. In extreme cases it was possible to conceive of the worm-wheel being fed with oil near its centre, the lubricant thus supplied finding its way through small radial holes to the spaces between the teeth. The worm-wheel would then become a centrifugal oil-pump and the teeth would be the delivery blades. It remained to be determined by experiment in what way the factor K was influenced by extreme velocities.

The Institution of Mechanical Engineers.

PROCEEDINGS.

FEBRUARY 1906.

The FIFTY-NINTH ANNUAL GENERAL MEETING was held at the Institution on Friday, 16th February 1906, at Eight o'clock p.m.; EDWARD P. MARTIN, Esq., President, in the chair.

The Minutes of the previous Meeting were read and confirmed.

The PRESIDENT announced that the following seven Transferences had been made by the Council:—

Associate Members to Members.

CRAWFORD, GERALD WALKER, ... Edinburgh.
EVANS, MALCOLM THOMAS, ... Bristol.
FLETCHER, JOSEPH ERNST, ... Dudley.
GIVEN, ERNEST CRANSTON, ... Liverpool.
HIGGINBOTHAM, GEORGE, ... Manchester.
McMAHON, JOHN JOSEPH, ... Manchester.
SIMPKIN, FRANK HENRY, ... Sheffield.

The following Annual Report of the Council was then read:—

ANNUAL REPORT OF THE COUNCIL

FOR THE YEAR 1905.

The Council have pleasure in presenting to the Members the following Report of the progress and work of the Institution during the past year.

During the year, His Majesty the King has conferred honours on the following Members of the Institution:—Lord Rayleigh, O.M., F.R.S., has been made a Privy Councillor; a Baronetcy has been conferred upon Mr. William B. Avery; a Knight Commandership of the Order of the Bath upon Mr. Philip Watts, F.R.S.; and a Knighthood upon Professor Alexander B. W. Kennedy, LL.D., F.R.S.

The total number on the roll of the Institution at the end of 1905 was 4,750, consisting of 9 Honorary Members, 2,427 Members, 1,748 Associate Members, 72 Associates, and 494 Graduates, which, as compared with 4,477 at the end of the previous year, shows a net gain of 273. During the past year 2 former members were re-instated and 477 candidates were elected. As 49 of these were formerly Graduates, and 4 withdrew after election, 426 fresh names were added to the register. The total losses were 153, made up of 52 deceases during 1904 (*see* Report of 1904), 67 resignations taking effect on 1st January 1905, and 34 removals.

The following forty Deceases of Members of the Institution were reported during the year 1905 :—

ASKHAM, PHILIP UNWIN,	Sheffield.
BARCROFT, HENRY (Associate),	Newry.
BLACK, WILLIAM,	Newcastle-on-Tyne.
BOEDDINGHAUS, JULIUS,	Düsseldorf.
BROGDEN, THOMAS,	Scarborough.
CAMPBELL, DANIEL,	London.
CAMPBELL, JAMES,	Leeds.
CARBUTT, Sir EDWARD HAMER, Bart.,	London.
CARTER, WILLIAM,	Chester.
CLARK, AUGUSTUS,	Pernambuco.
COLES, HENRY JAMES,	Derby.
DAVIS, ALGERNON HENRY (Associate Member),	Harrogate.
DEAN, WILLIAM,	Folkestone.
DORMAN, WILLIAM SANSOM,	Gloucester.
DRUMMOND, WALTER,	Glasgow.
EVANS, DAVID,	Saltburn-by-the-Sea.
FOSTER, JAMES,	Glasgow.
GREENWOOD, WILLIAM HENRY,	Birmingham.
GREW, FREDERICK,	London.
HEAD, ARCHIBALD POTTER,	London.
HOLLIS, SYDNEY AINSLIE (Associate Member),	Bloemfontein.
HORSLEY, CHARLES,	London.
HORTON, ENOCH,	Darlaston.
KIRKWOOD, JAMES,	Hong Kong.
MANSERGH, JAMES, F.R.S.,	London.
MARSHALL, FRANK THEODORE,	Newcastle-on-Tyne.
MORCOM, ALFRED,	Birmingham.
MORRIS, WILLIAM,	Cawnpore.
MORRISON, GABRIEL JAMES,	London.
PEACOCK, FRANCIS,	Tantah, Egypt.
RANSOME, JAMES EDWARD,	Ipswich.
SAMUELSON, Rt. Hon. Sir BERNHARD, Bart., F.R.S.	Banbury.
SCARLETT, JAMES,	Manchester.
SELLERS, WILLIAM,	Philadelphia.
SOUTHWELL, FREDERICK CHARLES.	London.
STEPHENSON, GEORGE ROBERT,	Cheltenham.
SUMNER, WILLIAM,	Manchester.
VERNON, WILLIAM HARRY (Associate Member),	Wakefield.
WALLACE, JOSEPH,	Trinidad.
WRIGHT, JOSEPH,	London.

Of these Sir Edward Carbutt was elected a Member in 1860, Member of Council in 1875, Vice-President in 1885, and President in 1887 and 1888. Sir Bernhard Samuelson, elected in 1865, was a Member of Council in 1883 and 1884; Mr. William Dean was elected a Member in 1868, and served as a Member of Council from 1892 till his death; Mr. Mansergh, elected in 1875, was a Member of Council from 1902; Mr. Morcom, elected a Member in 1897, served on the Council in 1898. Mr. William Sellers had been a Member since 1865, and Mr. G. R. Stephenson since 1868.

Owing to ill-health Mr. Henry D. Marshall resigned his seat on the Council after seventeen years' continuous service.

The Council appointed Mr. H. F. Donaldson, Mr. J. Rossiter Hoyle, and Mr. James Rowan, Members of Council for the remainder of the year to fill the three vacancies.

The Accounts for the year ended 31 December 1905 are now submitted (see pages 110 to 114), having been duly certified by Mr. Robert A. McLean, F.C.A., the Auditor appointed by the Members at the last Annual General Meeting.

The total revenue for the year 1905 was £12,713 10*s.* 9*d.*, inclusive of Entrance Fees £440 carried direct to Capital Account, while the expenditure was £11,093 8*s.* 11*d.*, leaving a balance of revenue over expenditure of £1,620 1*s.* 10*d.* A Special Fund has been formed, comprising two items of £250 each, received from Sir Edward Fry and the Metropolitan Water Board respectively, the interest on which it is intended to devote to some engineering purpose connected with the Institution. The financial position of the Institution at the end of the year is shown by the balance sheet. The total investments and other assets amount to £74,774 2*s.* 9*d.*, and, deducting therefrom the £25,000 of debentures and the total remaining liabilities, £2,367 14*s.* 1*d.*, the capital of the Institution amounts to £41,688 4*s.* 0*d.*, excluding the £5,408 L. and N. W. Railway 3 per cent. and the £2,000 Midland Railway 2½ per cent. Debenture Stocks set aside for the Leasehold and Debenture Redemption Fund. The remaining investments consist of £1,945 12*s.* Midland Railway 2½ per cent. Debenture Stock, £1,014 10*s.* 8*d.* Metropolitan

Water (B) 3 per cent. Stock, £674 L. and S. W. Railway 3 per cent. Consolidated Debenture Stock, and £1,000 Consols ($2\frac{1}{2}$ per cent.). The certificates of the securities have been duly audited by the Finance Committee and the Auditor.

Professor David S. Capper's Report of his elaborate experiments at King's College, London, extending over about eight years, was presented by the Steam-Engine Research Committee, under the Chairmanship of Mr. William H. Maw, at the March meeting, and the adjourned discussion thereon occupied the greater part of the April meeting. The consideration of any further research by this Committee has been postponed pending the completion of a Report to the Institution from the Steam-Jacket Research Committee under the Chairmanship of Mr. Henry Davey, by Professor T. Hudson Beare, of his experiments already carried out at University College, London, and at Edinburgh, and of some further experiments which he is intending to make at the new Engineering School of the Edinburgh University. Professor Beare's experiments were suspended during the greater part of the year, owing to pressure of work connected with building the new laboratories. These have now been completed, and Professor Beare hopes he will be able to present a Report during 1906.

The Alloys Research Committee, consisting of fifteen members under the Chairmanship of Sir William H. White, has met twice during the year. The research on the Properties of a Series of Iron-Nickel-Manganese-Carbon Alloys at the National Physical Laboratory was completed early in the year, and the Seventh Report of the Committee, embodying the results of this research, was presented and discussed at the November and December Meetings of the Institution. The discussion has been enriched by several written communications from foreign specialists. A research on the Alloys of Copper and Aluminium has now been begun; and in connection therewith Mr. J. D. Bonner, Dr. R. T. Glazebrook, F.R.S., and Mr. Leonard Sumner have been appointed to the Committee. This new research is intended to form the subject of

the Eighth Report of the Committee, and should be of great value to engineers.

The Gas-Engine Research in connection with the two specially constructed large gas-engines at the University of Birmingham is being carried on by Professor F. W. Burstall. The effect of changing the compression, other things being constant, is now being investigated. Special arrangements have been found necessary for dealing with the high compression, and the presentation of the next Report is therefore not expected during 1906. It is also intended to investigate the law governing the change of gas temperatures at various points within the cylinder. Sir Alexander B. W. Kennedy is the Chairman of this Committee.

The Council desire to record their thanks to those members and others who have presented books and other publications to the Library. Encouraged by the greater use made of the Library, about fifty new books on mechanical engineering have been purchased. A complete list of additions appears on pages 115–130.

With the cordial co-operation of the Liége Association of Engineers, the Annual Summer Meeting was held in Liége, June 19th–23rd. Six Papers were read and discussed, the majority of which were contributed by Belgian engineers. A Local Committee, consisting of members of the Liége Association of Engineers, arranged visits to the Exhibition, to various coal mines and works in the neighbourhood and to other towns in Belgium. The attendance at the Meeting was 220. The new Docks at Antwerp were visited on the return journey.

Monthly Meetings were held throughout the year, with the exception of May, July, August, and September. These Meetings were occupied with the reading and discussion of the following Papers:—

Some Impressions of American Workshops; by Mr. A. J. Gimson.
Waterworks Pumping Engines in the United States and Canada; by Mr. John Barr.

Some features in the Design and Construction of American Planing Machines; by Mr. Archibald Kenrick, Jun.

Engines at the Power-Stations, and at the St. Louis Exhibition; by Mr. Alfred Saxon.

First Report to the Steam-Engine Research Committee; by Professor David S. Capper.

Address by the President, Mr. Edw P. Martin.

Superheaters applied to Locomotives on the Belgian State Railways; by M. J. B. Flamme.

Electric Winding-Machines; by Professor Paul Habets.

Ferro-Concrete, and some of its most characteristic applications in Belgium; by M. Ed. Noaillon.

An Investigation to determine the effects of Steam-Jacketing upon the Efficiency of a Horizontal Compound Steam-Engine; by Mr. A. L. Mellanby, M.Sc.

The growth of Large Gas-Engines on the Continent; by M. Rodolphe E. Mathot.

The Strength of Columns; by Professor W. E. Lilly.

The Manufacture of Cartridge-Cases for Quick-Firing Guns; by Colonel Leandro Cubillo and the late Mr. Archibald P. Head.

Seventh Report to the Alloys Research Committee: On the properties of a series of Iron-Nickel-Manganese-Carbon Alloys; by Dr. H. C. H. Carpenter, Mr. R. A. Hadfield, and Mr. Percy Longmuir.

Behaviour of Materials of Construction under Pure Shear; by Mr. E. G. Izod.

The following Papers were accepted for publication in the Proceedings:—

Some Notes on American Woodworking Machinery; by Mr. W. Stanley Bott.

Notes on the Visit to America; by Mr. Charles Wicksteed.

Some Phenomena of Permanent Deformation in Metals; by Mr. G. H. Gulliver.

Photographs of Cutting-Tools in action; by Mr. J. F. Brooks.

Note on a Ten-wheels-coupled Tank-Engine on the Natal Government Railways; by Mr. John T. Hogg.

The Graduates held monthly Meetings during the Session 1904–05, and made four Visits to Works, including an excursion to Portsmouth. The average attendance was about 30 at the Meetings and 25 at the Visits. The following Papers were read and discussed:—

The Exhaust System of Dust Collecting, as applied to Grinding Machinery, etc.; by Mr. Vernon I. Norbury Williams.

New Electrical Swing-Bridge over Flood-Course of the River Weaver, Northwich, Cheshire; by Mr. T. P. B. Cliff.

Gas-Engine Testing; by Mr. A. C. Hess.

A Mechanical Method of Discharging and Storing Grain; by Mr. A. O. Laird.

The Type of Locomotive best suited to Heavy Express Trains; by Mr. J. R. Bazin.

Commercial Vehicles propelled by Internal-Combustion Engines; by Mr. Edward Reeve.

Design and Construction of Horizontal Engines; by Mr. A. B. Scorer.

The Papers by Mr. Bazin and Mr. Scorer have been awarded prizes by the Council.

At the February Meeting of the Graduates' Association, Mr. J. T. Nicolson, D.Sc., delivered an illustrated lecture on "Results of Force Measurements with Cutting Tools, and their Application to Lathe Design."

It is intended to hold the next Summer Meeting in Cardiff.

The result of the Ballot for the election of President, two Vice-Presidents, and seven Members of Council, to fill the vacancies caused by retirement, will be announced at the Annual General Meeting.

Dr. ACCOUNT OF REVENUE AND EXPENDITURE

Expenditure.

	£	s.	d.	£	s.	d.
To Expenses of Maintenance and Management—						
Salaries and Wages	2,884	17	0			
Postages, Telegrams, and Telephone	618	6	4			
Heating, Lighting, and Power	150	15	9			
Fittings and Repairs	141	5	4			
Housekeeping	124	8	2			
Incidental Expenses	51	6	11			
				3,970	19	6
,, Printing, Stationery, and Binding—						
Printing and Engraving Proceedings	1,841	8	10			
Stationery and General Printing	585	14	6			
Binding	36	5	2			
				2,463	8	6
,, Rent, Rates, Taxes, &c.—						
Ground Rent	875	17	2			
Rates and Taxes	822	17	6			
Insurance	28	4	0			
				1,726	18	8
,, Meeting Expenses—						
Printing	333	13	6			
Reporting	61	11	0			
Translations	49	9	6			
Travelling and Incidental Expenses	206	10	7			
				651	4	7
,, Conversazione				200	7	9
,, Dinner Expenses				61	17	0
,, Graduates' Prizes				9	15	8
,, Books purchased				60	12	1
,, Expenses in connection with Research Committees				445	14	9
,, Depreciation on Furniture and Fittings				62	10	5
,, Debenture Interest				1,000	0	0
,, Entrance Fees carried to Capital Account				440	0	0
Total Expenditure				11,093	8	11
,, Balance, being excess of Revenue over Expenditure (exclusive of value of Subscriptions in arrear), carried to Balance Sheet				1,620	1	10
				£12,713	10	9

FOR THE YEAR ENDED 31ST DECEMBER 1905. *Cr.*

Revenue.

		£ s. d.
By Subscriptions for 1905		11,024 0 0
" Subscriptions in arrear, paid in 1905		555 10 0
" Entrance Fees for 1905		440 0 0
" Rent of Upper Floor of Institution Building		415 12 6
" Interest, &c.—		
From Investments and Bank	126 3 7	
Income Tax refunded	12 14 4	
		138 17 11
" Reports of Proceedings—		
Extra Copies sold		139 10 4
		£12,713 10 9

Dr. **BALANCE SHEET**

	£	s.	d.	£	s.	d.
To Debentures—						
250 *of* £100 *each at* 4%, *redeemable in* 1917, *or at par at any date after* 1st *Jan.* 1908, *on six months' notice to holder*				25,000	0	0
„ Sundry Creditors—						
Accounts owing at 31st *Dec.* 1905 (*since paid*) .	1,563	18	0			
Unclaimed Debenture Interest (coupons not presented)	167	15	5			
				1,731	13	5
„ Subscriptions paid in advance				126	10	0
„ Willans Premium Fund (see page 114)				9	10	8
„ Special Fund (see page 114)				500	0	0
„ *Amount invested in* £5,408 *London and North Western Ry.* 3% *Debenture Stock, and* £2,000 *Midland Ry.* 2½% *Debenture Stock, with balance of interest thereon to be invested, set aside for Redemption of Debentures and Institution's Leasehold Property, see contra*				5,718	4	8
(*The Market Value of these investments and interest at* 31st *Dec.* 1905 *was about* £6,923.)						
„ Balance, being Capital of the Institution, exclusive of the Redemption and Sinking Fund :—						
Balance at 31st *Dec.* 1904	40,239	2	2			
Deduct—						
Further amount set aside for Redemption of Debentures and Institution's Leasehold Property, being amount of Life Compositions and Entrance Fees received during 1904	611	0	0			
	39,628	2	2			
Add—						
Excess of Revenue over Expenditure for the year ended 31st *Dec.* 1905 . .	1,620	1	10			
Amount received from Entrance Fees during 1905	440	0	0			
				41,688	4	0
				£74,774	2	9

Signed by the following members of the Finance Committee :—

EDWARD P. MARTIN.
W. H. MAW.
E. B. ELLINGTON.
HENRY DAVEY.

H. GRAHAM HARRIS.
J. F. ROBINSON.
MARK ROBINSON.

AT 31ST DECEMBER 1905. *Cr.*

			£ s. d.
By Cash—			
In Union of London and Smiths Bank—		£ s. d.	
On Deposit		1,100 0 0	
	£ s. d.		
,, Current Account . . .	1,114 17 0		
Add Paris draft not yet credited	3 0 0		
	1,117 17 0		
Less cheque outstanding . .	200 0 0		
		917 17 0	
		2,017 17 0	
In the Secretary's hands		28 2 11	
			2,045 19 11
,, Investments . . . . *Cost*			4,044 2 4
£ 1,945 12*s.* *Midland Ry.* 2½% *Debenture Stock.* 1,014 10*s.* 8*d.* *Metropolitan Water (B)* 3% *Stock.* 1,000 2½% *Consols.* 674 *L. & S. W. Ry.* 3% *Consolidated Deb. Stock.* *The Market Value of these investments at* 31*st Dec.* 1905 *was about* £4,047.			
,, Investment of Amount set aside for Redemption of Debentures and Institution's Leasehold Property, *see contra* . . .			5,718 4 8
£5,408 *London and North Western Ry.* 3% *Debenture Stock, and* £2,000 *Midland Ry.* 2½% *Debenture Stock, cost* £5,616 15*s.* 1*d.* *with* £101 9*s.* 7*d.* *balance of interest thereon to be invested.* *These investments with their accumulating interest are set aside for the above purpose.*			
,, Subscriptions in arrear, *not valued.*			
,, Furniture and Fittings (*less depreciation*)			1,187 17 7
,, Books in Library, Drawings, Engravings, Models, Specimens, and Sculpture (*estimate of* 1893)			1,340 0 0
,, Amount in Union of London and Smiths Bank to meet unclaimed Debenture Interest (*coupons not presented*) . .			167 15 5
,, Proceedings—stock of back numbers, *not valued.*			
,, Institution House . . . . *Cost*			60,270 2 10
			£74,774 2 9

I certify that all my requirements as Auditor have been complied with, and I report to the Members that I have audited the above Balance Sheet, dated the 31st December 1905, and in my opinion such Balance Sheet is properly drawn up and exhibits a true and correct view of the state of the affairs of the Institution as shown by its Books.

ROBT. A. McLEAN, F.C.A.,
Auditor,
1 Queen Victoria Street, London, E.C.

19*th January* 1906.

K

WILLANS PREMIUM FUND.

Investment £159 8s. 5d. of India 3% Stock . . . . cost £165 5s. 0d.

Dr.	£ s. d.	Cr.	£ s. d.
To Balance, held in trust .	9 10 8	By Interest, 1904 . . .	4 15 4
		,, Do. 1905 . . .	4 15 4
	£9 10 8		£9 10 8

Audited, certified, and signed by the names on pages 112-113.

(For the Declaration of Trust, *see* Proceedings 1901, page 16.)

SPECIAL FUND.

(*The object to which this Fund will be devoted is under consideration.*)

Dr.	£ s. d.	Cr.	£ s. d.
To Amount held in trust	500 0 0	By donations, 1905—	
		,, Sir Edward Fry . .	250 0 0
		,, Metropolitan Water Board	250 0 0
	£500 0 0		£500 0 0

Audited, certified, and signed by the names on pages 112-113.

LIST OF ADDITIONS TO THE LIBRARY.

BOOKS (in order received).

Agricultural and Industrial Problems in India, by Professor Alfred Chatterton; from the author.

Machine Shop Companion; Sketches of Engine and Machine Details; from the author, Mr. Wallace Bentley.

Mechanics Applied to Engineering, by Professor John Goodman; from the author.

Elements of Railway Economics, by W. M. Acworth; from the Delegates of the Clarendon Press.

Practical Dictionary of Mechanics (4 vols.), by E. H. Knight: from Mr. Henry Chapman.

Insulation of Electric Machines, by H. W. Turner and H. M. Hobart; from the publishers.

Cowlyd Waterworks, by T. B. Farrington; from the author.

French and English Pocket Dictionary, by John Bellows.

"Machinery," Vol. XIV, 1898; "Invention," Vol. XXII, 1898; "Elektrizität," 1891; from the British Fire Prevention Committee.

Marine Engines and Boilers, their Design and Construction, by Dr. G. Bauer and L. S. Robertson; from Mr. L. S. Robertson.

Trades Waste: its Treatment and Utilisation, by W. Naylor.

Steam Turbines (English translation), by Dr. A. Stodola, translated by L. C. Loewenstein.

Petrol Motors and Motor Cars, by T. H. White; from the author.

Theory and Practice of Modern Framed Structures, by J. B. Johnson, C. W. Bryan, and F. E. Turneaure.

Design of Beams, Girders, and Columns in Machines and Structures, by W. H. Atherton; from the author.

Constructional Steelwork, by A. W. Farnsworth; from the author.

Chemins de fer d'Alsace (Atlas), by MM. Bazine and Chaperon; Life of Sir M. I. Brunel, by Richard Beamish; Treatise on the Steam-Engine, by John Bourne; Mill Work and other Machinery (Text and Plates), by Robertson Buchanan; Practical Illustrations of Land and Marine Engines and Boilers, by N. P. Burgh; Practical Treatise on Screw-propulsion, by N. P. Burgh; Britannia and Conway Tubular Bridges (2 vols. 8vo, and

Plates folio), by Edwin Clark; Traité de l'art de la Charpenterie (2 vols. 4to., and Plates folio), by A. R. Émy; The Great Britain Atlantic Steamship, by T. R. Guppy; Imperial Cyclopædia of Machinery, by William Johnson; Traité de la Chaleur (Text 8vo., Plates folio), by E. Péclet; Working Drawings and Designs in Mechanical Engineering and Machine-making, by W. Walker, A. B. Brown, F. Lightbody, R. Davis, and R. S. Burn; Shipbuilding, theoretical and practical, by I. Watts, F. K. Barnes, W. J. M. Rankine, and J. R. Napier; from Mr. P. J. Cowan.

Concrete-Steel, by W. N. Twelvetrees; from the author.

Central South African Railways, Report of the General Manager of Railways for the year ended 31 December 1904, by T. R. Price; from the author.

Technological Dictionary, English-German-French (3 vols.), by Messrs. Hoyer and Kreuter.

Ganot's Physics, translated by E. Atkinson, edited by A. W. Reinold.

Steam Boilers: their History and Development, by H. H. P. Powles; from the author.

Sir Henry Bessemer, F.R.S., an Autobiography; from the publishers.

Hampton's Scholastic Directory for London and Provinces; from the publishers.

Études Pratiques de Météorologie des Stations de Beaulieu, Sèvres et Vacquey, 1903 (with Atlas); Dix années d'Observations Météorologiques à Sèvres (Seine-et-Oise), 1892–1901 (with Atlas); Observations Courantes en Météorologie et Comparaison des Stations de Beaulieu, Sèvres et Vacquey; from the author, M. Gustave Eiffel.

Congrès International des Mines, Liége, 1905—Section de Mécanique Appliquée, Tome I; from Mr. Edgar Worthington.

Machine Construction and Drawing, by Frank Castle; from the author.

Report on Steam Turbines, by Admiral G. W. Melville and J. H. Macalpine; from Admiral G. W. Melville.

Practical Trigonometry, by Henry Adams; from the author.

Small Destructors for Institutional and Trade Waste; Refuse Disposal and Power Production; from the author, Mr. W. F. Goodrich.

The Civil Engineer and Architect's Journal, Vols. VI, VII and IX; from Mr. J. G. O'Connell.

Gas-Engines and Producer-Gas Plants, by R. E. Mathot (translated by W. B. Kaempffert); from the author.

Fowler's Electrical Engineer's Year Book; Fowler's Mechanical Engineer's Pocket Book; from the author, Mr. W. H. Fowler.

Light Railways at Home and Abroad, by W. H. Cole.

Sewage Disposal Works, by W. S. Crimp.

Ore and Stone Mining, by Sir C. Le Neve Foster (revised by B. H. Brough).

Microscopic Analysis of Metals, by Floris Osmond (edited by J. E. Stead).

Locomotive Engineering, by W. F. Pettigrew.

Introduction to the Study of Metallurgy, by Sir W. C. Roberts-Austen, K.C.B., D.C.L., D.Sc., F.R.S.
Hydraulic Power and Hydraulic Machinery, by Henry Robinson.
Lectures on Iron-founding, by Thomas Turner.
Marine Steam-Engine, by R. Sennett and H. J. Oram.
Railway Appliances, by Sir J. Wolfe Barry, K.C.B.
Practical Shipbuilding (Text 8vo., Plates folio), by A. C. Holms.
Modern Engines and Power Generators, vols. II–VI, by Rankin Kennedy.
Structural and Field Geology, by James Geikie, LL.D., D.C.L., F.R.S.
Modern Foundry Practice, by John Sharp.
American Tool Making and Interchangeable Manufacturing, by J. V. Woodworth.
Construction of the Modern Locomotive, by George Hughes.
Mineral Oils and their By-products, by I. I. Redwood.
The Richards Steam-engine Indicator, by C. T. Porter.
Calculus for Engineers, by John Perry, D.Sc., F.R.S.
Engineering Contracts and Specifications, by J. B. Johnson.
Public Works of Great Britain, edited by F. W. Simms.
Cements, Limes, and Plasters, by E. C. Eckel.
Ordinary Foundations, including the Cofferdam process for Piers, by C. E. Fowler.
Modern Electric Practice, vols. I–VI, edited by Magnus Maclean.
Earth and Rock Excavation, by Charles Prelini.
Water Supply of Towns and the Construction of Waterworks, by W. K. Burton.
Refrigerating and Ice-making Machinery, by A. J. Wallis-Tayler.
Tin Deposits of the World, by Sydney Fawns; from the author.
Cotton Gins and Ginneries, by B. P. Dobson; from the author.
Telegraphy, by T. E. Herbert; from the publishers.
Nouvelles Orientations Scientifiques, by J. Pin y Soler; from Señor Fernando Alsina.
Aluminium, by J. W. Richards.
Handbook on British Patents for Inventions; from Messrs. Day, Davies and Hunt.
Practical Telephone Handbook, by Joseph Poole; from the publishers.
Chemistry as applied to Arts and Manufactures (7 vols.), by Dr. Sheridan Muspratt; Application of Cast and Wrought Iron to Building purposes, by William Fairbairn; from Mrs. Gjers.
Electric Railways, by S. W. Ashe and J. D. Keiley.
Hardening, Tempering, Annealing and Forging of Steel, by J. V. Woodworth.
Gas Engine Construction, by H. V. A. Parsell and A. J. Weed.
Baedeker's Belgium and Holland.
Reinforced Concrete Construction, by A. W. Buel and C. S. Hill.

Acetylene, by V. B. Lewes.
Electric Furnaces and their Industrial Applications, by J. Wright.
Gas-Engine Design, by C. E. Lucke.

OFFICIAL PUBLICATIONS.

Annual Report of the Government Mining Engineer for the years ending 30 June 1903 and 30 June 1904; from the Transvaal Mines Department.

Twelfth and Thirteenth Reports of the Ontario Bureau of Mines, 1903 and 1904 (Parts I and II); from the Director.

Annual Report of the Columbian Minister of Mines for the year ending 31 December 1904; from the Minister.

General Index to the Reports of Progress, 1863–1884; Summary Reports of the Geological Survey Department of Canada for the years 1898 to 1904; from the Geological Survey of Canada.

Tests of Metals, &c., 1903 and 1904; Report of the Chief of Ordnance, 1904; from the Government of the United States of America.

Twenty-fifth Annual Report, 1903–1904; Monograph, XLVII; Mineral Resources of the United States, 1903; Bulletins, 191, 234–240, 242–246, 248–250, 252–255, 257, 262; Water Supply and Irrigation Papers, Nos. 119–122, 124, 126, 128, 132; from the U.S. Geological Survey.

Report of the Chief Inspector of Mines in India, under the Indian Mines Act (VIII of 1901), for the years ending 31 December 1903 and 31 December 1904; from the Government of India.

Australian Official Journal of Patents; from the Department of Patents in the Commonwealth of Australia.

Report of the Department of Public Works for the year ended 30 June 1904; Statistical Account of Australia and New Zealand, 1903–4, by T. A. Coghlan; Annual Report of the Department of Mines, 1904; Report of the Railway Commissioners for the year ended 30 June 1905; from the Government of New South Wales.

Gold-Fields of Victoria, Monthly Report; Geological Survey Bulletins, 15–17; from the Government of Victoria.

Supplement to Government Gazette of Western Australia; Year Book, 1902–4, by Malcolm A. C. Fraser; West Australian Mining Industry; Geological Survey, Bulletins, 2–13, and 15; Report on the working of the Government Railways and the Roebourne-Cossack Tramway, 30 June 1904; Report of the Royal Commission on the Ventilation and Sanitation of Mines; from the Government of Western Australia.

PAMPHLETS, &c.

History of the Ibstock Colliery (Private) Railway, by C. E. Stretton; from the author.

Edward Entwistle, Oldest living Engine-driver; from Mr. John Barr.

The New Patent Rules, by Sir W. Lloyd Wise; from the author.

Die Firma David Grove von 1864–1904; from Mr. David Grove.

Opening Address of the President, Mr. G. G. M. Hardingham, to the Chartered Institute of Patent Agents; from the author.

Tangential Water Wheels; Investigation of the Doble Needle Regulating Nozzle, by H. C. Crowell and G. C. D. Lenth; from the Abner Doble Co.

The Inch, The Metre, and the Metric System, by Thomas Parker, F.R.S.E.; from the author.

Die Formelzeichen, by Olof Linders; from Messrs. Jäh and Schuuke.

Regulations relating to the construction and use of Boilers in the Dutch Eas Indies, by W. W. Campbell; from the author.

Specialization in Manufacture, by A. E. Outerbridge, Jun.; from the author.

The Great Thames Barrage, by T. W. Barber; from the author.

Filetages Universels système Aubaile, Théorie et Pratique, by Alexis Aubaile; from the author.

A West African Smelting House, by C. V. Bellamy; from the author.

Electrical Operation of Textile Factories, by H. W. Wilson; from the author.

Kupfer, Zinn und Sauerstoff, by E. Heyn and O. Bauer; from the publisher.

Memorandum on the Construction and Verification of a new copy of the Imperial Standard Yard, Part I, by H. J. Chaney, I.S.O.; from the author.

Land Area Computation made easy, by W. Codd; from the author.

University of Oxford: Diploma in Scientific Engineering and Mining Subjects; from the Secretary to Committee.

Coal Mines Regulation Acts, 1887: Special Rules for the Installation and Use of Electricity; from the Secretary of State, Home Department.

London Building Acts (Amendment) Bill 1905; from the London County Council.

Conditions affecting the Force of Waves and the Construction of Breakwaters to resist them; Investigation of the Methods best suited for Surmounting great Differences of Level between the Reaches of Canals; from the author, Mr. L. F. Vernon-Harcourt.

Permanent International Association of Navigation Congresses, Papers presented at Milan Congress, &c.:—Monografia storica dei Porti dell' Antichità nella Penisola Italiana; Le Segnalazioni Marittime; Apparatus for Raising and Lowering Ships (system Pokorný), by Ferdinand Pokorný; Projet d'Élévateur de Bateaux, by M. Wilhelm; Mitteilung der Teltowkanal-

Bauverwaltung über die Machnower Schleuse, by Ingenieure Havestadt and Contag; La Législation et la Jurisprudence Italienne par rapport aux Fleuves et aux Torrents Navigables, by Édouard Sassi; Die neuen wasserwirtschaftlichen Gesetze in Preussen, by Dr. Ing. Sympher; Milano nel 1905; List of Members, 1905; Regulations; Report of the Executive Committee, 31 July 1905; Catalogue of the Publications; from Mr. L. F. Vernon-Harcourt.

Practical Notes on Waterworks Construction, by G. H. Hughes; from the author.

Cumberland Coal Field and Its Creators, by J. C. Tipton; from the American Association Incorporated.

El Puerto de Buenos Aires, by L. A. Huergo; from the author.

An Enquiry into and an Explanation of Decimal Coinage and the Metric System of Weights and Measures, by Edwyn Anthony; from the author.

Application of Dry Air Blast, by James Gayley; Experiments relating to the Effect on Mechanical and other Properties of Iron and its Alloys produced by Liquid Air Temperatures, by R. A. Hadfield; Rare Elements, by E. L. N. Armbrecht; Some Refinements of Mechanical Science, by Ambrose Swasey (Presidential Address to American Society of Mechanical Engineers, 1904); from Mr. Edgar Worthington.

Aperçu sur la Mouture Moderne; La Surchauffe appliquée à la Machine à vapeur d'eau; from the author, M. François Sinigaglia.

Steel: its Manufacture and Classification, with special reference to Hardening and Tempering, by R. B. Hodgson; from the author.

Laws and Rules relating to Patents, Designs, and Trade-marks, by W. Silver Hall; from the author.

Armed Concrete Lattice-girder (system Visintini), by Max Emer and Dr. Fritz von Emperger; from the publishers.

Armoured Concrete Constructions (Edmond Coignet system), by Edmond Coignet; from Mr. Henry Chapman.

A Comparison of Different Types of Steam Turbine, by R. M. Neilson; from the author.

Design of Concrete-Steel Beams, by W. N. Twelvetrees; from the author.

Losses in Non-Condensing Engines, by J. B. Stanwood; from the author.

British and American Coal-cutting Machines, by A. S. E. Ackermann; from the author.

Plan de la Ville d'Anvers.

Notice sur la Ville et le Bassin industriel de Liége.

Théorie expérimentale de la Machine à vapeur, by V. Dwelshauvers-Dery; from the author.

Aluminium-Zinc Alloys, by E. S. Shepherd; Tensile Strength of Copper-Tin Alloys, by E. S. Shepherd and G. B. Upton; from Mr. E. S. Shepherd.

La Machine à Piston Chauffé (système N. François)—Description et Essais, by H. Hubert; from the author.

On the Magnetic Qualities of some Alloys not containing Iron, by J. A. Fleming and R. A. Hadfield; from the authors.

Wire Ropes used for Winding, by J. A. Vaughan and W. Martin Epton; from the authors.

Extension of the Dewey Decimal Classification; from Professor L. P. Breckenridge.

Notes on Engineering Workshop Organisation, by Douglas T. Heap; from the author.

Accidents due to the Asphyxiation of Blast-Furnace Workmen, by B. H. Thwaite; from the author.

Opening of Stockton and Darlington Railway (Reprints of public notices of); from Mr. Henry Nicholson.

The Inch and the Metre; from Mr. Thomas Parker, F.R.S.E.

Régulateurs organes de réglage et volants des machines; Oscillations des locomotives sous l'action de diverses forces perturbatrices; Oscillations des véhicules de chemin de fer à l'entrée en courbe et à la sortie; Oscillation des véhicules de chemin de fer sur leurs ressorts de suspension; from the author, M. Georges Marié.

Presidential Address to the South Staffordshire Iron and Steel Institute, 1905. by Walter Jones; from the author.

The Return Pipe System of Compressed Air Power Transmission, by H. C. Behr; from the author.

Use of Gas for Power and Heating, by E. A. Dowson; from the author.

Notes on Dock Construction, by G. C. Kenyon; from the author.

Report on Gas and Electricity, by J. F. Simmance; from the Town Clerk, Edinburgh.

Presidential Address to the Institution of Civil Engineers, 1905, by Sir Alexander R. Binnie; from the Institution.

The following from the Engineering Standards Committee:—No. 5, Report of the Locomotive Committee on Standard Locomotives for Indian Railways; No. 10, British Standard Tables of Pipe Flanges; No. 11, British Standard Specification and Sections of Flat-Bottomed Railway Rails; No. 12, British Standard Specification for Portland Cement; No. 13, British Standard Specification for Structural Steel for Shipbuilding; No. 14, British Standard Specification for Structural Steel for Marine Boilers; No. 16, British Standard Specifications of Tables for Telegraph Material; No. 19, Report on Temperature Experiments on Field Coils of Electrical Machines carried out at the National Physical Laboratory. No. 20, British Standard Screw Threads; No. 21, British Standard Pipe Threads for Iron or Steel Pipes and Tubes; No. 22, Report on the Effect

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40 Blue Prints of American Locomotives, &c.; from Mr. Edgar Worthington.

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North of England Institute of Mining and Mechanical Engineers, Newcastle-on-Tyne; Transactions.

Patent Agents, Chartered Institute of; Transactions.

Permanent Way Institution; Proceedings.

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South Wales Institute of Engineers, Cardiff; Proceedings.
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The Chamber of Commerce Journal (from Mr. Henry Chapman).
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The Export Review.
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The Foundry Trade Journal and Pattern-Maker.
The Journal of Gas Lighting.
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The Hardware Trade Journal.
Ice and Cold Storage.
Imperial Institute Bulletin (from Mr. Henry Chapman).
Irish Builder and Engineer.
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Iron Trade Circular, Ryland's.
The Ironmonger.
Knowledge and Illustrated Scientific News.
Locomotive Magazine.
London University Gazette.
The Machinery Market.
The Marine Engineer.
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Revue Universelle des Mines.

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Canadian Engineer.

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L'Industrie.
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India.

The Indian and Eastern Engineer.
Railways.
Indian Textile Journal (English edition).

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Giornale del Genio Civile.

United States.

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American Manufacturer.
The Automobile.
Brotherhood of Locomotive Firemen's Magazine.
Electrical Review.
Electrical World and Engineer.
Electricity.
The Engineer.
Engineering News.
The Engineering Record.
The Iron Age (from Mr. W. H. Maw).

The Iron Trade Review.
Machinery.
Marine Engineering.
Marine Review.
Popular Mechanics.
The Railway and Engineering Review.
Railway Master Mechanic.
Street Railway Review.

ADDITION TO MUSEUM.

A section of pipe, almost blocked by scale, used for circulating hot-water (from the River Trent); from Mr. John Goff.

The President moved the adoption of the Annual Report, and invited discussion thereon.

Mr. R. W. Allen thought it must be a source of great satisfaction to the Members to see the large amount of balance on the year's working, namely £1,620 1*s.* 10*d.*, and he asked what became of this money. He also desired to know what had been done with the balance of last year.

The President explained that the balances had been invested in Debenture Stocks.

No other remarks being made, the Report was unanimously adopted.

The PRESIDENT then presented the prizes to the two Graduates who had been successful in obtaining the award—Mr. J. R. Bazin for his Paper on "The Type of Locomotive best suited to Heavy Express Trains," and Mr. A. B. Scorer for his Paper on "Design and Construction of Horizontal Engines."

The PRESIDENT reported the resignation of Mr. Harry Lee Millar, who had acted for twenty years as Honorary Treasurer, and announced that the election of a new Treasurer would take place at the next Meeting.

The PRESIDENT reported that the Ballot Lists for the election of Officers for the present year had been opened by a Committee of the Council; and the Secretary read the list of those found to be duly elected, as follows :—

PRESIDENT.

EDWARD P. MARTIN, ... Abergavenny.

VICE-PRESIDENTS.

JOHN A. F. ASPINALL, ... Manchester.
A. TANNETT-WALKER, ... Leeds.

MEMBERS OF COUNCIL.

H. F. DONALDSON, ... Woolwich.
J. ROSSITER HOYLE, ... Sheffield.
HENRY LEA, ... Birmingham.
MICHAEL LONGRIDGE. . . . . Manchester.
JOHN F. ROBINSON, ... London.
JAMES ROWAN, ... Glasgow.
JOHN W. SPENCER, ... Newcastle-on-Tyne.

The Council for the present year is therefore as follows:—

PRESIDENT.

EDWARD P. MARTIN, ...	Abergavenny.

PAST-PRESIDENTS.

SAMUEL WAITE JOHNSON, ...	Nottingham.
Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S., ...	London.
WILLIAM H. MAW, ...	London.
E. WINDSOR RICHARDS, ...	Caerleon.
PERCY G. B. WESTMACOTT, . . .	Ascot.
Sir WILLIAM H. WHITE, K.C.B., LL.D., D.Sc., F.R.S., ...	London.
J. HARTLEY WICKSTEED, ...	Leeds.

VICE-PRESIDENTS.

JOHN A. F. ASPINALL, ...	Manchester.
EDWARD B. ELLINGTON, ...	London.
ARTHUR KEEN, ...	Birmingham.
Sir WILLIAM T. LEWIS, Bart., . . .	Aberdare.
T. HURRY RICHES, ...	Cardiff.
A. TANNETT-WALKER, ...	Leeds.

MEMBERS OF COUNCIL.

Sir BENJAMIN BAKER, K.C.B., K.C.M.G., LL.D., D.Sc., F.R.S., . . .	London.
Sir J. WOLFE BARRY, K.C.B., LL.D., F.R.S., .	London.
HENRY CHAPMAN, ...	London.
GEORGE J. CHURCHWARD, ...	Swindon.
HENRY DAVEY, ...	London.
H. F. DONALDSON, ...	Woolwich.
H. GRAHAM HARRIS, ...	London.
EDWARD HOPKINSON, D.Sc., . . .	Manchester.
J. ROSSITER HOYLE, ...	Sheffield.

Henry A. Ivatt, ...	Doncaster.
Henry Lea, ...	Birmingham.
Michael Longridge, ...	Manchester.
The Rt. Hon. William J. Pirrie, LL.D.,	Belfast.
Sir Thomas Richardson, ...	Hartlepool.
John F. Robinson, ...	London.
Mark H. Robinson, ...	Rugby.
James Rowan, ...	Glasgow.
John W. Spencer, ...	Newcastle-on-Tyne.
Sir John I. Thornycroft, LL.D., F.R.S.,	London.
John Tweedy, ...	Newcastle-on Tyne.
Henry H. West, ...	Liverpool.

The President reminded the Members that at the present meeting the appointment had to be made of an auditor for the current year.

Mr. Henry Carrick moved: "That Mr. Robert A. McLean, F.C.A., 1 Queen Victoria Street, London, be re-appointed to audit the accounts of the Institution for the present year, at the same remuneration as last year, namely, twenty-five guineas."

Mr. William Schönheyder seconded the motion, which was carried unanimously.

The following Paper * was read and partly discussed :—

"Large Locomotive Boilers;" by Mr. George J. Churchward, *Member of Council*, of Swindon.

The Meeting terminated at Ten o'clock. The attendance was 196 Members and 101 Visitors.

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* *See* Proceedings 1906, Part 2, page 165.

THE NIAGARA FALLS POWER-STATIONS.

EPITOME OF A LECTURE

By Professor W. CAWTHORNE UNWIN, LL.D., F.R.S.,
Honorary Member,

AT THE GRADUATES' MEETING.

Monday, 12th February 1906.

Edward P. Martin, Esq., *President*, in the Chair.

Along the boundary between Canada and the United States there is a chain of great lakes having a surface of 90,000 square miles, Plate 3, and receiving the drainage from a catchment area of 240,000 square miles, an area more than twice that of Great Britain and Ireland. These lakes form great reservoirs, from which there is a remarkably uniform outflow through the St. Lawrence River to the Atlantic. The lakes taken in order are Lake Superior, Lake Michigan, Lake Huron, Lake Erie, and Lake Ontario. The surface level of the lakes is the same except at two points. Between Lake Superior and Lake Huron there is a drop of about 18 feet at the Saulte St. Marie. For navigation this drop is overcome by canals on the American and Canadian sides through which passes a very large traffic. It is stated that 27 million tons pass through these canals annually, or a tonnage between two and three times as great as that which passes through the Suez Canal. That is of some importance in connection with the power-stations, in this way, that it is only in a district where

there are great industrial and commercial interests that such large schemes can be expected to be successful. The other change of level is between Lake Erie and Lake Ontario, which are connected by the Niagara River, the total drop between the lakes being 326 feet. The distance between the lakes is about 30 miles, but almost all the fall is in the last 15 miles. There is a fall of about 56 feet in the rapids above the Niagara Falls, about 160 feet at the Falls and 110 feet below the Falls.

The whole drainage of the upper lakes flows from Erie through the Niagara River into Ontario, and thence by the St. Lawrence River to the Atlantic. The lakes act as storage reservoirs, so that the volume of flow and the levels in the Niagara River are remarkably constant. In extreme cases the river-level above the Falls varies $3\frac{1}{2}$ feet, the alteration being chiefly due to wind holding back the outflow from the lakes. Below the Falls the river-level varies at most 15 feet, the alteration being due to ice-blocks formed in the lower river which are generally of short duration.

The ordinary discharge of the Niagara River is about 250,000 cubic feet per second, or about 6,000 tons per second. If the total fall between the lakes could be utilized 7,000,000 H.P. would be available, and at the Falls themselves about 4,000,000 H.P. is available. All this energy has till recently been wasted in fluid friction, the only effect produced at the Falls being that the temperature in the lower river is raised about one-fifth of a degree Fahrenheit.

The falls consist of the Horseshoe Fall on the Canadian side and the American Fall on the other side, Plate 4, the two being separated by Goat Island. The Horseshoe Fall is about one-third of a mile wide, and the American Fall 600 feet. Below the Falls the river flows through a ravine 200 to 400 yards wide, and 200 to 300 feet deep. This gorge has been cut by the action of the river itself, and the edge of the Falls is still receding. The mean recession annually, from surveys made from 1842 to 1890, is 0·64 foot at the American Fall and 2·14 feet at the Horseshoe Fall. One part of the Horseshoe Fall has receded about 280 feet in 48 years, or nearly 6 feet per year. Lyell calculated, at a time when the observations were not

very complete, that it must have taken 35,000 years for the excavation of the ravine below the Falls. But even so, the Niagara River must be a very modern river, and there is no doubt that at one time the outflow from the lakes took another direction. The main cause of the rather rapid recession of the Falls is the geological structure of the district. A bed of strong limestone, 90 feet thick, overlies a bed of rather easily disintegrated shale. By the action of the falling water on the shale the limestone is undermined and breaks down in masses.

Most of the early exploration of Canada was carried out by French officers, missionaries, and traders. Jacques Cartier, in his second voyage to the St. Lawrence, heard of a great cataract in 1535. In "L'Histoire de la Nouvelle France," published in 1609, the existence of a great fall on the trade route to the West is mentioned. In 1669, the distinguished French explorer, La Salle, entered the lower Niagara River in a 10-ton vessel, and though he did not proceed to the Falls he realised the importance of the possession of the mouth of the Niagara River to trade interests. One of La Salle's companions, Father Hennepin, reached the Falls in 1678, and he afterwards published a description and view of the Falls in an account of his travels ("Nouvelle Découverte," 1697). His description is worth quoting:—"Betwixt Ontario and Erie there is a vast and prodigious cadence of water, which falls down after a surprising and astonishing manner, insomuch that the Universe does not afford a parallel. The waters which fall from this horrible precipice do foam and boil after the most hideous manner imaginable, making an outrageous noise, more terrible than that of thunder. When the wind blows out of the south their dismal roaring may be heard 45 miles off." In 1679 La Salle constructed a block house at the mouth of the Niagara River and shortly after built a ship, the "Griffon," on the upper river. In 1725–6 the French built Fort Niagara at the mouth of the river, and by means of it retained control of the western trade route and of the Indian tribes settled round the Falls. Its possession was the deciding factor in determining whether trade went to the English at New York or to the French at Quebec. In 1759, it was captured

after a siege by the English, who held it till 1783, after which it passed to the United States. The importance of this station in connection with the fur trade was very great, and for nearly a hundred years the policy of England and France in those regions, and the efforts of their armies and colonial officers centred on the possession of Fort Niagara. In the war of 1812 the Niagara region was again the scene of conflict, Fort Niagara was recaptured by the English, and one of the hardest-fought actions of the campaign in Upper Canada took place near the Falls. Fort Niagara was finally ceded to the United States in 1815. As late as 1800, when John Maude visited the Falls, there was only a small village at the now thriving town of Buffalo, and there were still 2,000 Indians, Senecas and Cayugas, settled in the neighbourhood of the Falls.

The construction of the Erie and Welland Canals, and more recently of the Georgian Bay Canal, are more recent efforts to maintain the western trade route and to overcome the obstacle presented by the Niagara escarpment. Ships of considerable size can now pass from the upper lakes to the St. Lawrence, and by it and its canals to the Atlantic.

About 1883 both the United States and the Canadian Governments had become ashamed of the degraded condition of the Falls in consequence of the construction of water-mills and unsightly buildings on almost every available part of the shores of the river near the Falls. The United States appointed a distinguished engineer, Mr. Evershed, to see what could be done, and at his instance the buildings were purchased and destroyed and a national park or reservation was formed on the American side. Similar action was shortly after taken by the Canadian Government at the instance of Lord Dufferin on the other side, and thus the beauty of the neighbourhood of the Falls was restored and secured permanently.

Early Utilization.—The importance of the Falls as a source of energy was recognised from an early period. The first important effort to obtain power was made in 1861, when the so-called hydraulic canal, Plate 3, was constructed, 35 feet in width, 8 feet in depth and 4,400 feet in length, from a point above the upper

cataracts to a basin at the top of the bluff below the Falls. On the bluff were constructed mills, having turbines supplied with water from the basin and discharging it through short tunnels on the face of the bluff. In these cases only part of the available fall was utilized, water being plentiful and the cost of excavating pits for the turbines considerable. In 1885 about 10,000 H.P. was utilized in this way, or the whole available supply of the hydraulic canal.

When engaged in forming the reservation Mr. Thomas Evershed considered the possibility of utilizing part of the power of the Falls, in a way which would not interfere with the amenities of the immediate surroundings, but in a more effective manner and on a larger scale than the works then existing at Niagara. There were then at Holyoke and other manufacturing towns cases where water was supplied to various mills on a high level, working turbines erected by the mill-owners, the tail water of which was discharged into canals on a lower level. The construction of the canals, dams, and other hydraulic works was carried out by a water company who were repaid by a rental on the water used by the mills. Mr. Evershed's proposal was to acquire land about a mile and a half above the Falls, and to construct surface-supply canals and a tail-race tunnel leading to the lower river. Mill-owners were to be granted sites and the right to take water from the surface canals and to discharge it into the tail-race tunnel, putting in their own hydraulic machinery. Mr. Evershed considered that at most 4 per cent. of the water passing over the Falls would be sufficient for the largest probable development. The project was taken up by very strong financial people, and in 1886 they obtained a charter giving the right to utilize 200,000 H.P. on the American side, and a little later they obtained the further right to develop 250,000 H.P. on the Canadian side.

It was clear to those concerned that such a project could only be successful if undertaken on a very large scale. The cost of the canal and tunnel, reckoned per H.P. utilized, would be small enough only when the total power rendered available was very large. But the plan adopted was a very bold one for that time. Ten considerable manufacturing towns in the United States were found

to use less than 100,000 H.P. for all requirements. Three of them, Lowell, Lawrence, and Holyoke used only 20,000 H.P. At Buffalo, the nearest large town, coal cost only 7*s.* a ton, and the cost of steam power to mill-owners was very moderate. At that time there was no instance of electrical distribution of power to various consumers, and electric traction and electro-chemical industries were in their infancy. Nevertheless a surface canal 250 feet wide, 12 feet deep, and 1,700 feet long, and a tail-race tunnel discharging into the lower river 21 feet high, 19 feet wide and 7,000 feet long, were commenced. These works were adequate for developing 100,000 H.P. Then a long and serious investigation was commenced to find out the best method of utilizing the power which could be thus made available. A large paper-mill using 8,000 H.P. was erected, which put in its own turbines, and this was the first concern to use the new source of power and the only one at the present time carried out on Mr. Evershed's original plan.

The result of much consideration in Europe and America was the resolution to distribute the Niagara power electrically.

The hydraulic part of the project did not present great difficulty. Although probably no turbine had then been constructed of more than 1,000 H.P., designs were obtained for turbines of 5,000 H.P. It was resolved to adopt turbines of Swiss design, of 5,000 H.P., each placed at the bottom of a slot excavated in the rock and driving dynamos on the ground-level by vertical shafts, Plate 5. Adequate guarantees were obtained both as to efficiency and as to speed regulation.

The earlier plans for electric distribution were not so satisfactory, and controversy arose as to the use of continuous or alternating current. With continuous current high voltage can only be obtained by generators in series, which present difficulties of insulation. The voltage of continuous current can only be changed by rotary transformers, which are costly and require attention when running. A continuous-current system is comparatively inelastic in adaptation to various uses. On the other hand, alternate current can be more easily generated at high voltage;

the voltage can be changed in static transformers requiring little supervision and comparatively cheap; lastly, when required, direct current can be obtained in motor transformers. The alternate current system is elastic, lending itself to very various requirements. At first the weight of authority was in favour of a continuous-current system, but ultimately it was decided to generate alternate current. The governing consideration proved to be the importance of uniformity and interchangeability of the generating units, so that any generator and its turbine could be put on any part of the load. In power-house No. 1 electricity is generated at 2,200 volts at 25 periods per second, two-phase.

Periodicities of 70 and 100 were common in this country and 133 in America; but for polyphase motors a lower periodicity was desirable. Every great scheme at Niagara has now adopted a periodicity of 25. Low periodicity gives greater efficiency in the motors, diminished resistance in long circuits, less leakage by brush discharge, and less tendency to break down the insulators. For transmission to Buffalo it was found that three-phase current would permit a material economy of copper in the transmission line. A method was found for changing two-phase into three-phase current in the static transformers. In the later schemes at Niagara the current is generated directly as three-phase current.

The general arrangement of the schemes which are now actually under construction is shown in Plate 4, and these may now be described in detail.

The Niagara Falls Power Company on the American Side (Plates 4 to 9).—This company began work in 1890 and first delivered electricity in 1895. It has now two power-houses. Power-house No. 1, Plate 5, has ten units of 5,000 H.P. each, generating two-phase current at 2,200 volts 25 periods. The wheel slot is 178 feet long and 178 feet deep and the effective fall is 136 feet. The turbines, Plates 5 and 6, are twin outward-flow turbines, designed by Messrs. Faesch and Picard of Geneva, and built in America, with penstocks $7\frac{1}{2}$ feet diameter. The turbines run at 250 revolutions per minute. The vertical turbine shafts are hollow, of $\frac{3}{4}$-inch rolled tube, 38 inches

diameter, with solid bearings 11 inches diameter. The turbines are regulated by cylindrical sluices which rise and fall on the outside of the wheels. The dynamos, Plate 7, have external revolving field magnets and an internal stationary armature. The local distribution of electricity is by underground cables at the generator voltage. There is an intermediate transmission by overhead conductors at 11,000 volts. The long-distance transmission to Buffalo is three-phase at 22,000 volts. There are three circuits to Buffalo, two with copper and one with aluminium conductors. The loss is about 10 per cent. when 30,000 H.P. is transmitted. At Buffalo there is a three-phase underground distribution at 10,000 volts to the principal sub-transformer stations. From Tonawanda there is a branch circuit to Lockport, 15 miles distant, supplying current for the Erie Railway.

The adaptation of the system adopted to different purposes is shown by the fact that at the present time the Niagara Falls Power Company delivers to consumers 25-cycle alternating current, three, two, or single-phase, at voltages from 22,000 to 30. Also 60-cycle current, two-phase and single-phase, at 8,000 to 110 volts; 125-cycle current for arc-lighting at 8,000 and 2,200 volts: and lastly, direct current at 100, 160, 250, 350 and 8,000 volts. About 70,000 H.P. is now daily distributed from the two power-houses.

In power-house No. 2, turbines designed by Messrs. Escher Wyss, of Zurich, Plate 8, are installed. These are single, inward-flow turbines, each of 5,500 H.P., with bronze wheels and cylindrical sluices and suction pipes. The other arrangements are similar to those in the first power-house.

In these power-houses the weight of each turbine wheel and shaft is about 35 tons, and that of the revolving field ring of the dynamo about 35 tons; altogether 70 tons, which could not be carried on any pivot or collar-bearing at the speed of the turbines. In power-house No. 1 water-pressure acts on the cover of the upper turbine and is relieved from acting on the lower turbine, giving an upward force of 65 to 70 tons to balance the weight. The excess pressure is taken by a collar-bearing. In power-house No. 2, with radial flow

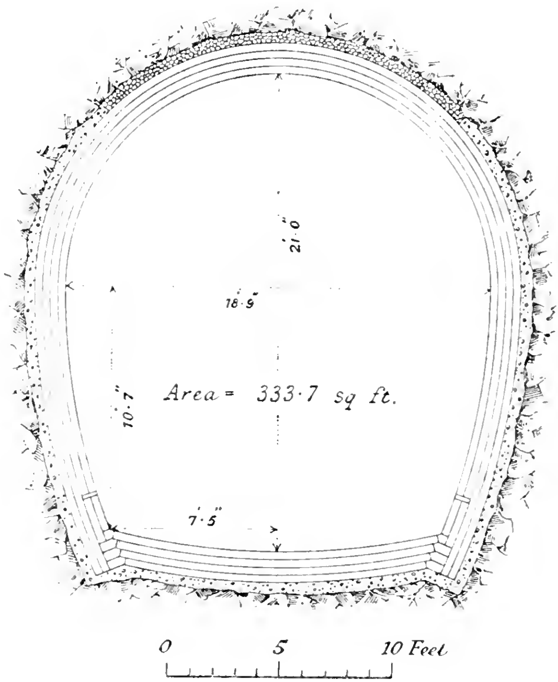
turbines, another arrangement is necessary. A special piston is provided, 4 feet 6 inches diameter, the water-pressure on which, due to the head, balances the weight, Plate 8. The excess unbalanced load in this case is taken by the bearing shown in Plate 9, oil being forced between the bearing surfaces.

The most difficult problem in designing was the speed-regulation, which required to be very efficient for driving alternators in parallel. Steam-engines using a light fluid can be easily regulated by governors acting direct on throttle or expansion valves. It is different with water-turbines using a fluid of great inertia. In one of the Niagara penstocks there is about 400 tons of water flowing at 10 feet per second, opposing great resistance to any quick variation of flow. The governor in power-house No. 1 consists of a sensitive governor acting on a ratchet relay. The governor puts one or other of two rachets in gear with the rachet-wheel connected with the sluices. The rachets reciprocate being driven by the turbine. According as one or other ratchet is in gear the sluices are raised or lowered. In power-house No. 2 the relay is an hydraulic relay. This is shown in principle in Plate 9, which however is not exactly the arrangement adopted at Niagara. In this case the sensitive governor G opens a valve and puts in action a ram driven by oil from an oil reservoir at a pressure of 1,200 lbs. per square inch. One millimètre of movement of the governor sleeve fully opens the relay valve, and the ram moves the turbine-sluice with a force of 50 tons. An automatic sluice relieves any excess pressure in the penstock due to water-hammer action. The tendency to hunt present in relay governors is prevented by a subsidiary arrangement. The ram of the relay as it moves forward gradually closes, by lowering the fulcrum end *f* of the lever, which rests on the wedge *w*, the relay valve, which admits pressure oil, unless the sensitive governor reopens it. The turbine sluices can be completely opened or shut in 12 seconds. The ordinary variation of speed is not more than 1 per cent. The momentary variation if all the load is thrown off is not more than 5 per cent.

The Canadian Niagara Power Company (Plates 4, 10, 11 and 12).—The installation of this Company will be worked in combination

with that of the Niagara Falls Company, so that it can assist when necessary the works on the other side of the river. The works were not started on the Canadian side till it was thought that all the problems involved had been satisfactorily solved by experience on the American side. When complete the power-house will have

THE CANADIAN NIAGARA POWER CO.
Cross-Section of Tunnel.

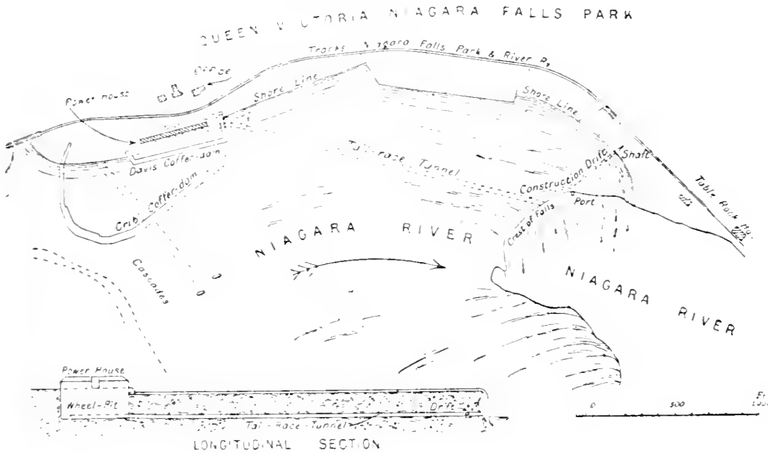


eleven units of 10,250 H.P. each, on 133 feet effective fall. Five turbines, Plates 10 and 11, are now installed. The turbines are double inward-flow turbines with suction-pipes. The tail-race tunnel shown in cross-section above is 2,200 feet long, 21 feet high by 19 feet wide, and the water will flow at 27 feet per second. The wheel slot, Plate 12, is 570 feet long, 165 feet deep, and 18 feet wide. The generators are three-phase, 11,000 volts, 25 cycles with

internal revolving field. The weight of turbine-wheel shaft and field ring is 120 tons, which is carried by a balancing piston, on which water acts at the pressure due to the fall.

The Electrical Development Company of Ontario (Plates 4, 13 and 14).—The success of the Niagara Falls Power Company has stimulated other enterprises of similar magnitude. The Development Company of Ontario obtained rights and are erecting an installation of 125,000 H.P. on the Canadian side (see general plan). In order

THE ELECTRICAL DEVELOPMENT CO. OF ONTARIO.
General Plan of Works.



to construct a masonry intake dam in the river, a cribwork cofferdam, Plates 13 and 14, was built in some of the worst of the upper rapids, 600 feet long, and laying bare eleven acres of the river-bed. This temporary dam was at the worst part in water 24 feet deep, and flowing at probably 30 miles an hour. Its construction was an engineering feat of the greatest boldness. Within it is now being erected a concrete gathering dam with granite coping to direct water into the intake, while floating ice will pass over the dam and back into the river. The tail-race tunnel, Plate 14, 26 feet high, $23\frac{1}{2}$ feet wide, and 1,900 feet long, passes right under the upper rapids and discharges underneath the Horseshoe Fall. A drift-way to the

mouth of the tunnel was first driven and then the tunnel excavated back from the mouth. The excavated material was thrown down from the mouth of the tunnel into the lower river, where it has disappeared. The wheel slot is 416 feet long, 27 feet wide, and 150 feet deep. It is to receive eleven turbines of 12,500 H.P. each. The generators are 8,000 kw., giving three-phase currents at 25 cycles, 12,000 volts. It is intended to transmit most of the current from this station to Toronto, a distance of 85 miles. A right of way has been obtained along which the transmission lines will pass, and an electric railway will be constructed. Two lines of steel towers are being erected 46 feet high and 400 feet apart. These carry the conductors along which the current will be transmitted as three-phase current at 60,000 volts.

The Ontario Power Company on the Canadian Side (Plates 4, 15, 16, 17 and 18).—The plans of this company differ essentially from the others, and are no doubt partly conditioned by the fact that the ground nearer the Falls was already occupied. The intention is to develop 200,000 H.P. The intake is at the top of the rapids on the Canadian side near the Dufferin Islands, Plate 4. The intake is specially designed with reference to ice difficulties. The openings in the intake dam, Plate 15, have a curtain dipping 9 feet into the water. The flow to the turbines is under the curtain, the floating ice being carried past. A second curtain on the same principle is constructed between the fore bay and inner basin, and the ice in the outer basin is carried forward over the lower part of the outer dam. The ice in winter is a serious difficulty at Niagara. Cake ice floats down from the upper lakes and " mush " or " frasie " ice is formed in the turbulent rapids primarily by the freezing of spray and foam. For ice in this latter form there are screen frames.

From the intake three great steel conduits, Plate 16, 18 feet and 20 feet in diameter, convey the water round the other power-houses to the top of the bluff below the Falls. These conduits, of which one is already constructed, are of ½-inch steel plates, stiffened with bulb irons and encased in concrete. The velocity in the conduits will be 15 feet per second. There is a spillway, Plate 15, at the

end, formed by a weir to prevent water-hammer in the pipes. The flow over the weir passes down through a helical culvert or spillway in the rock to the lower river. From the conduits the water will be taken down to the turbines through twenty-two steel pipes, 9 feet in diameter, passing down the face of the bluff.

The power-house in course of erection is on a platform at the foot of the bluff and just above the level of the lower river. The turbines, Plates 17 and 18, are to be inward-flow, twin turbines, each of 12,000 H P. under 175 feet head. The axis of the turbines is horizontal and the shaft 24 inches diameter. The turbine wheels are 78 inches diameter and have movable guide-blades, which are more efficient than the cylindrical sluices used in the other power-houses, though of course economy of water is not of great importance at Niagara. The generators on the turbine shafts are three-phase, 25 period, 12,000 volt alternators, and run at 187½ revolutions per minute.

From the power-house electric cables run back through a tunnel in the rock to a transformer and distributing station at the top of the bluff.

The Niagara Falls Power and Manufacturing Company.—This is a development of the original hydraulic canal scheme on the American side, Plates 3 and 4. The hydraulic canal has been much enlarged, and in 1895–6 a second power-house was erected with turbines of 35,000 H.P. under 210 feet head. Now a third power-house is being erected to develop 100,000 H.P. These power-houses are at the foot of the bluff below the Falls, and take water through the hydraulic canal and from a basin at the top of the bluff.

Other schemes for utilizing power have been projected, and to a certain extent rights have been obtained subject to the fulfilment of conditions. Of these one of the most interesting is to take water from the Chipewa River above the falls on the Canadian side, the flow in the river being reversed. A canal across the top of the Niagara escarpment would convey the water to a point from which it could be carried down to a power-house near Lake Ontario. None of these plans have passed beyond the stage of projects. In the case of

the works which have been described, though most of them will be for some time incomplete, the costly headworks and tail-race tunnels are being constructed for the full intended development. This indicates a strong confidence that a demand can be created for the enormous amount of power which will be available when all these schemes are completed.

Destruction of the Falls.—Evershed believed that the maximum probable demand on the water of the Niagara River would not exceed 4 per cent. of the mean flow, which may be taken at 222,000 cubic feet per second. Probably at present there is an actual development of 150,000 H.P., which on 160 feet fall and for an efficiency of 0·75 involves the abstraction of 11,000 cubic feet per second of the water. This amounts to 5 per cent. of the mean flow and perhaps to 7 per cent. of the minimum flow. But the works in progress, if carried to their full intended development, will utilize 650,000 H.P. and require 48,000 cubic feet per second. This amounts to 21½ per cent. of the mean flow and perhaps 30 per cent. of the minimum flow. Obviously when the works are complete there will be a serious alteration in the appearance of the Falls.

If the water used for the Welland Canal, the Chicago Drainage Canal and other projected canals, is taken into account, the diversion will probably amount to 41 per cent. of the minimum flow. Recently, the public, both in Canada and the United States, have become alarmed at the prospect of the ruin of the appearance of the Falls, and it is proposed that there should be an International Committee appointed by the governments concerned, to consider the question as to whether any further diversion of the water should be permitted, and as to whether charters already granted, under which at present no works have been executed, should be cancelled.

The Lecture was illustrated by numerous lantern slides and wall diagrams, some of which are illustrated in the accompanying Plates* 3 to 18, and 2 Figs. in the letterpress.

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* Several of the illustrations are reproduced by kind permission of the American Institute of Electrical Engineers, and the Cassier Magazine Co.

MEMOIRS.

CHARLES LOWTHIAN BELL was the second son of the late Sir Lowthian Bell, and was born at Washington Hall, the seat of his father near Durham, on 24th March 1855. He was educated first at a preparatory school at The Mount, Northallerton, and subsequently at Wellington College. After leaving Wellington he proceeded to Paris and continued his studies at the École des Mines, whence he went to the well-known works of Schneider and Co., at Le Creusot, where he remained about a couple of years. He then returned to England, and, after occupying various subordinate positions in the firm of Messrs. Bell Brothers, he undertook the management of the furnaces at Walker-on-Tyne in the year 1881. Three years later he removed to Clarence as Assistant Manager under Mr. John Thompson. On the death of this gentleman in 1887 he became manager of the Clarence Works, and under his superintendence the whole arrangements were re-modelled, Cowper firebrick stoves being substituted for pipe stoves, and the blowing machinery and boiler plant entirely reconstructed to permit the utilization of the waste heat for the manufacture of salt. In addition to these important changes, a by-product coke-oven plant was erected by Messrs. Bell Brothers in conjunction with the German Actien-Gesellschaft für Kohlendestillation, the elaborate arrangements for sorting and washing the coal required for this plant being planned by him. He remained in charge of the Clarence Works until 1904. Shortly before his father's death in December of that year he decided to resign his position and to take a less active part in the management though he remained a director of the Company.

Following in the footsteps of his father, he paid numerous visits to ironworks abroad, both in Europe and America, accompanying his father on one of his visits to the latter country. On the flotation of

Messrs. Bell Brothers, Limited, in 1899, as a public company he and Mr. W. H. Panton paid another visit to America to study the processes of steel manufacture in that country, and they also visited various works in Europe for the same purpose. The information then acquired was utilized in designing the steel plant at Clarence. Already in 1886 the attention of Sir Lowthian Bell and his partners had been turned in the direction of the manufacture of steel from Cleveland iron, and a small plant had been erected under designs, in the preparation of which Mr. C. L. Bell took a large part. A considerable quantity of steel was produced at this establishment, but circumstances prevented the project being carried forward and for some years the works lay idle. In 1898, by arrangement with Messrs. Dorman, Long and Co., experiments which the latter firm had begun at Rosebery Steel Works, near Middlesbrough, were continued at the works at Clarence, put at the disposal of the firm by Sir Lowthian Bell and his sons. Under the direct supervision of Mr. W. H. Panton, assisted by Mr. C. L. Bell, a series of experiments resulted in a satisfactory solution of the problem, the flotation of the firm as a public company and the erection of the present important plant at Clarence being the direct results of these operations.

Over and above the many activities he displayed in connection with the Works at Clarence (where not only the Iron Works, but also the Salt Works and Soda Works until they were sold to the Salt Union, and Messrs. Brunner, Mond and Co., respectively, were under his control), he took an active part in the volunteer movement. He joined the North Riding Volunteer Artillery in 1874 and took command of the Corps in 1895 as Lieutenant-Colonel, becoming a year later the Honorary Colonel, resigning his command in 1902 on reaching the age limit. During the South African War he was the means of raising and equipping two Colt-gun detachments and of sending out 400 men for the Imperial Yeomanry. He was for some time a member of the Middlesbrough Town Council, serving the office of Mayor in the year 1893, when he welcomed the Members of this Institution on the occasion of their Summer Meeting *; and he

* Proceedings 1893, page 217.

was for many years an active member of the Stockton Board of Guardians. He was on the Commission of the Peace for the North Riding and for the County of Durham, and also for the Borough of Middlesbrough. His death took place at his residence near Middlesbrough, after a very short illness, on 8th February 1906, in his fifty-first year. He became a Member of this Institution in 1885.

OSWALD BROWN was born in London on 22nd April 1848, being the son of the late Mr. Joseph Brown, C.B., K.C. He was educated at Brighton College and King's College, London. In 1866 he was articled to Messrs. James Simpson and Co., of Pimlico, and the first important work of which he had charge for this firm was the erection and starting of machinery for the Berlin Water Works during 1867 and 1868. He was next appointed assistant engineer to the Servian Copper and Iron Co., and at the latter end of 1870 he erected the Sulina Lighthouse at the mouth of the Danube for the European Commission of the Danube, acting under Sir Charles Hartley. During the next eighteen months he was back again in London with Messrs. Simpson and Co., and from 1872 until the end of 1876 he was the resident engineer in charge of the Galatz Water Works. During this period he designed water works for Bucharest, Jassy, and Ibraila. Subsequently he was for a short time mechanical Engineer to the Royal Sardinian Railway Co. It was, however, in Australia that he carried out the chief work of his career. In 1878 he was appointed hydraulic engineer to the South Australian Government. At that time scientific water-supply was unknown in that part of the world, and the work was strongly opposed by a political party; but, being carried out, resulted, after four years' working, in the reduction of the water rate by nearly 50 per cent., accompanied by an increase in revenue of nearly 100 per cent. The Adelaide water scheme undoubtedly formed the basis of subsequent Australian schemes, and in the designing of some of these his advice was solicited. In 1882 he resigned his appointment and returned to England. After undertaking certain special work in the south of France, he started in practice as a consulting engineer in

Westminster, being retained by the South Australian Government. He designed the Pernambuco Water Works, and became consulting engineer to several others on the Continent, and frequently advised on schemes for drainage, sewage farming, and hydraulics generally. In the course of his life he was a great traveller, and especially in the early portion of his career had many varied and interesting experiences. He was essentially a man to be called in on difficult and complex cases; and his professional work drifted more and more into the re-organizing of business concerns which required drastic reform. Latterly his health had shown signs of failing, and his death took place in London on 10th February 1906, in his fifty-eighth year. He became a Member of this Institution in 1884; and he was also a Member of the Institution of Civil Engineers.

FREDERICK GEORGE CASTLE was born at Dewsbury, Yorkshire, on 8th November 1859. In 1873 he commenced work at Messrs. Mark Oldroyd and Co.'s Works in the same town, leaving in October 1884 to attend the Royal College of Science, South Kensington, as a teacher-in-training during 1884 to 1886. From 1886 to 1888 he was an assistant in the Mechanics and Mathematics Division. In the latter year he was appointed assistant master at the East London Technical College, and became chief assistant in the Preparatory Day College and assistant lecturer in the Engineering Department. His death took place on 3rd February 1906, in his forty-seventh year. He became an Associate of this Institution in 1889.

GEORGE DOVE was born at Derwenthaugh, Co. Durham, on 3rd March 1817. In 1830 he became an apprentice at Messrs. R. and W. Hawthorn's Works, Newcastle-on-Tyne, and on the completion of his term he entered the drawing-office of Messrs. Hawks, Thompson and Co., of Gateshead, and later became manager for Messrs. Thompson Brothers, of Wylam-on-Tyne, both of these firms being prominent locomotive-engine makers of the period. While thus engaged, he built some of the earliest engines used on the Newcastle and Carlisle, Brunton and Shields, and other railways. In 1842 he became chief engineer for Messrs. Losh, Wilson and

Bell at their Walker Iron Works, of which the late Sir Lowthian Bell was general manager, and during this time he designed the first of the blast-furnaces at Walker and Clarence Works. In 1857 he became a partner in the firm of Cowans, Sheldon and Co., of Carlisle, which had until then carried on business at Woodbank, near Carlisle. In 1857 the firm purchased the works at St. Nicholas, Carlisle, and the management of this branch of the business was undertaken by Mr. Dove. On the conversion of the business into a company in 1873, he became managing director, the duties of which office he actively fulfilled until within a short time of his death. In municipal affairs he took a great interest, being a member of the Carlisle Town Council from 1873 till 1891, and was offered the mayoralty in 1886, but declined the honour. He was also a city magistrate. His death took place at his residence at Stanwix, near Carlisle, on 22nd January 1906, in his eighty-ninth year. He became a Member of this Institution in 1857.

William Edward Miles was born at Copenhagen on 22nd August 1860, and was educated at the East London Collegiate School. He received his technical education at the City of London College from 1876 to 1878. During this period he served an apprenticeship in the shops and drawing office of Messrs. Humphrys, Tennant and Co., marine engineers, Deptford, London. On its completion in 1881 he remained with the firm for one year in the drawing office. In the following year he was employed in the drawing office of Messrs. Oswald Mordaunt and Co., engineers and shipbuilders, of Southampton; and from 1883 to 1885 he acted as engineer to Messrs. Tatham and Co., shipowners of London. In 1885 he received an appointment in the drawing office of the Royal Gun Factory, Woolwich, being chiefly engaged on the design of breech mechanism of the large naval guns. In 1891 he was appointed principal foreman of the engine branch, with charge of the power plant; and when the authorities decided to equip the Royal Gun Factory with motors for electric driving, his branch was made responsible for the installation and maintenance of the plant. In 1903 he was promoted to the rank of Assistant Manager,

and held this position at the time of his death, which took place, after a short illness, on 19th February 1906, in his forty-sixth year. He became a Member of this Institution in 1904.

JAMES STABLER was born at Barnard Castle on 5th September 1825. He was educated at Staindrop, and, having at an early age developed an inclination for mechanical pursuits, he was apprenticed to the Stockton and Darlington Railway Co. at their Shildon Works. On the completion of his apprenticeship, he went to Scotland and was engaged on the Edinburgh, Perth, and Dundee Railway until 1851 when he obtained employment at Messrs. R. and J. Longridge's Works at Bedlington, Northumberland. At the end of the same year he went to Messrs. Maudslay, Sons and Field's Works at Lambeth, London; and later on became engineer to Messrs. Hodges, of the Distillery, Lambeth. In 1855 he was appointed foreman of the fire-engine works of Messrs. Shand, Mason and Co., where he remained until 1860. After an interval of two years, during which he was manager to Messrs. Morton and Co., Liverpool, he returned to Messrs. Shand, Mason and Co., and became a partner in the firm. On their behalf he travelled extensively in the principal countries of Europe and in the United States and Canada, until 1879 when he retired. In 1882 he started in business on his own account as a consulting engineer, principally to Messrs. F. Braby and Co., of London, Glasgow, Liverpool, Bristol and Dunkirk, and to the London Zinc Mills Co. He also acted for many years as London agent for Messrs. Daniel Adamson and Co., of Dukinfield, Manchester. In 1887 he invented an improved railway crossing, and in 1903 brought out some improvements connected with steam-boilers. His death took place in London on 5th March 1906, in his eighty-first year. He became a Member of this Institution in 1869; and was also a Member of the London Association of Foremen Engineers.

ARCHIBALD THOMAS STURGESS was born at Bedale, Yorkshire, on 25th April 1857. He was educated at a private school at Tunbridge Wells, from 1867 to 1870, and then went to Mannedorf, Lake Zurich,

for two years, returning to Tunbridge Grammar School in 1872. On leaving school in 1875 he acted as secretary to his father in the estate office of the Earl of Ancaster at Empingham, Rutland, during which period he was trained in surveying and levelling. In 1878 he went to Penshurst Park, Kent, and was engaged in the preparation of plans for cottages on the estate. Having a liking for mechanical engineering, he erected and equipped a private workshop, and in this pursuit he received encouragement from the late Mr. James Nasmyth, who was a friend of his father's. In 1879 he went as a pupil to the late Mr. J. H. Hutchinson, civil engineer and contractor, at Nicosia, Cyprus, where he assisted in carrying out several large contracts, the most notable being the construction of a large military barracks, afterwards used as government offices in Nicosia. In 1883 he started on his own account as engineer and contractor in Larnaca, Cyprus, where amongst other work he designed and erected the offices and staff quarters of the Eastern Telegraph Co. In 1886 he returned to London, and in the following year went to Madrid, becoming a partner in the firm of Messrs. Parsons, Graepel and Sturgess, machinery merchants, and taking charge of the technical department. In 1891, on its dissolution, he joined with Mr. W. Foley as senior partner in the firm of Messrs. Sturgess and Foley. He devoted a great portion of his time to designing and carrying out electrical installations in Madrid, Cartagena, Burgos, Rio Tinto, and many small towns. In 1895 the firm undertook, under his direct supervision, an important irrigation work near Toledo. For leading the joints of the piping, he invented a pot for melting the lead which was carried along the top of the pipe by light rails and at each joint running off the necessary amount of lead, the pot being then filled up with the amount of lead for another joint. This apparatus was very successful and proved most economical. In the year 1900 the firm undertook a contract for the Pure Salt Co., near Saragossa, for supplying and erecting the milling and other machinery, and for all their buildings and offices, and he personally superintended the carrying out of the work. During 1904 and 1905 the firm undertook another large irrigation contract, which necessitated the making of a canal of about two miles in length with

all its requisites in the way of pumping plant. His death took place at his residence in Madrid on the 11th February 1906, in his forty-ninth year. He became a Member of this Institution in 1903.

JOSEPH WALLACE was born at Ceres, Fifeshire, on 27th February 1846. He served his apprenticeship with Messrs. Douglas and Grant, of Kirkcaldy, at the time that firm took up the application of the Spencer and Inglis type of Corliss valve-gear to their stationary engines. In that service he acquired considerable experience in the erection of such engines in all parts of Scotland. While engaged in that way near Glasgow about the year 1868, and for the sake of enlarging his experience, he entered the service of Messrs. W. and A. McOnie, manufacturers of sugar machinery, where he was soon entrusted with the charge of their light erecting and machine shops. In 1880 he was appointed Chief Engineer by Messrs. Charles Tennant, Sons and Co., over their sugar estates in Trinidad, British West Indies. In those days these properties, some sixteen or eighteen in number, were nearly all run as separate concerns which grew their own canes, crushed them in single mills, and worked up the juice in a primitive style into the muscovado quality of sugar. But during the twenty years Mr. Wallace was in that employment the number of establishments was gradually reduced, and a process of centralizing went on so that practically only two factories are now in operation, the canes or the juice being brought into them by light railways, or pipe lines, and worked up by modern methods into yellow crystals for the London market. In 1900 the connection with Messrs. Tennant was severed, but he continued to live in Trinidad. While on a visit to Cuba his death occurred in Havana on 22nd April 1905, at the age of fifty-nine. He became a Member of this Institution in 1895.

The Institution of Mechanical Engineers.

PROCEEDINGS.

March 1906.

An Ordinary General Meeting was held at the Institution on Friday, 16th March 1906, at Eight o'clock p.m.; T. Hurry Riches, Esq., Vice-President, in the chair.

The Chairman announced that the President, owing to indisposition, was unable to attend the Meeting, and in his absence he (Mr. Riches) had been called upon to take the chair.

The Minutes of the previous Meeting were read and confirmed.

The Chairman announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following eighty-four candidates were found to be duly elected:—

MEMBERS.

Chamen, William Ashcombe,	Cardiff.
Fowler, Thomas Walker,	Melbourne.
Grimshaw, George William,	Preston.
Layton, Henry Edward,	Bilbao.
MacGregor, James,	Sheffield.
Macmillan, Hugh,	Port Louis, Mauritius.
Morrison, William Lazonby,	Valparaiso.
Napier, John Stewart,	Paisley.

N

Pearson, James, ...	Bombay.
Pringle, Percival John, . .	Burton-on-Trent.
Roberts, Gervase Henry, . .	Woolwich.
Skelton, Reginald William, Engineer-Lieut. R.N.	Plymouth.

ASSOCIATE MEMBERS.

Abbott, Alfred Ernest, . .	Wolverton, Bucks.
Aird, James Erskine, . . .	Sylhet, Assam.
Bayntun, Robert Somerville, . .	Birkenhead.
Carrington, George, . . .	Chesterfield.
Carter, Harold Herbert, . .	Basingstoke.
Carter, Walter, ...	Manchester.
Charlton, Arthur Edwyn, . .	Shanghai.
Clark, Robert George, . . .	Cardiff.
Cooper, George Seton Halcott, .	Pietermaritzburg.
Cryer, James Wilfred, . . .	Bolton.
Dawe, Philip Henry, . . .	London.
Devey, Arthur Charles, . .	London.
Donaldson, James Alexander, .	Glasgow.
Edwards, John, ...	Oporto.
Evans, Ernest Alfred, . . .	Midland Junc., W. Australia.
Fox, Francis Henry Wright, . .	London.
Hodge, John, ...	Morro Velho, Brazil.
Hodgetts, George William, . .	Sydney, Cape Colony.
Holdsworth, Walter, . . .	Tipton.
Holt, Robert Bickerstaffe, . .	Leeds.
Hornett, William George, . .	Nagpur.
Horsnell, Thomas, . . .	London.
Hosegood, Tom Presant, . .	Bristol.
Hyne, Harry Everett, . . .	Morriston, Glam.
Isaac, Gwilym Bertram, . .	Carmarthen.
Job, Norris Henry, . . .	Thornaby-on-Tees.
Jones, Stanley Peters, . . .	Liverpool.
Jopling, Arthur, ...	Sunderland.
Lambert, James Graham, . .	London.

Lander, Albert Jesse, . . .	London.
Lee, Ralph Arnt Edward Bernard,	Bombay.
Lewis, Paul Alexander, . .	Wolverhampton.
Lord, Frank, ...	Warrington.
Mangold, Charles August, . .	Port Elizabeth.
McCulloch, Philip George, . .	Perth, W. Australia.
Michael, Hubert, ...	Johannesburg.
Nandi, Kali Charan, . . .	Glasgow.
Newman, Charles William Durie, .	London.
Plante, Stanley Gedge, . .	London.
Robertson, James French, . .	Howrah, India.
Robson, George, ...	Dowlais.
Roose, FitzRoy Owen Jonathan, .	London.
Sharp, William, ...	Howrah, India.
Simper, William Alfred, . .	London.
Starkie, James Edmund, . . .	Burnley.
Symonds, Percival Herbert, . .	Manchester.
Taylor, Charles Edward, . .	Chelmsford.
Thompson, John Archibald, . .	London.
Tresham, Lancelot David, . .	London.
Underwood, Albert Leopold, . .	London.

GRADUATES.

Bremner, Allan James, . . .	London.
Chivell, William Richard, . .	London.
Clarke, Russell Balfour, . .	London.
Cowie, John Robert, . . .	Alloa.
Field, Eustace Reginald Wilkins, .	Birkenhead.
Fish, John Blair, ...	Calcutta.
Fraser, Thomas Charles, . .	London.
Friend, Ernest John, . . .	London.
Gordon, Vivian, ...	London.
Green, Charles William Tandy, .	London.
Greenway, Noel Wilson, . .	Birmingham.
Hardinge, Henry Malcolm, . .	Rangoon.
Hart-Davis, Hugh Vaughan, . .	Erith.

LAWSON, JOHN HESLIN, ...	London.
MOSS, ERNEST WILLIAM, ...	London.
ODELL, JOSEPH WILLIAM EWART, . .	London.
PAYNE, FRANK JOSEPH, ...	London.
SHAW, ARCHIBALD THOMAS, . . .	London.
SPINK, HAROLD MARSHALL, . . .	London.
WOOD, CECIL GORDON, ...	Gainsborough.
WORSSAM, RALPH, ...	London.
YORK, REGINALD STANLEY, ...	Doncaster.

The CHAIRMAN announced that the following three Transferences had been made by the Council:—

Associate Members to Members.

BELL, JAMES ALEXANDER, ...	Aberdeen.
O'GORMAN, MERVYN, ...	London.
TRAFFORD, ALFRED, ...	Manchester.

The CHAIRMAN said the next duty he had to perform was one of pleasure, not unmixed with a certain amount of regret, because he was sorry the President was not able to attend to make the presentation on behalf of the Institution to Mr. Harry Lee Millar, who had for twenty years been the Treasurer of the Institution. Mr. Millar had been a friend of the Institution for so many years that it was impossible to let the present occasion pass without tendering to him some symbol of the kindly feeling which the Council and the Members felt towards him for all his services to the Institution during such a long period. Mr. Millar's principal duty had been to hold the uninvested funds of the Institution, and as the banker of the Institution the funds could not have been left in better hands. Mr. Millar had not been perhaps an active member in the technical proceedings, but he had been

nevertheless an absolute essential to the well-being of the Institution, and had done his duty so kindly and so well that he was sure all the members would join with him in wishing Mr. Millar the best of all good things; and now that he had retired, after a long life of hard work, he was sure they all hoped he would enjoy rest and comfort, and every possible happiness for the days which he was spared to live. He had the pleasure on behalf of the members and the Council to present to Mr. Millar a case of cutlery and a cheque for £45 as a small memento of their regard and esteem for him and his good work. The inscription on the face of the case was as follows:—"Presented to Harry Lee Millar by the President, Council, and Members of the Institution of Mechanical Engineers, on his retirement from office of Honorary Treasurer, the duties of which he faithfully performed during twenty years, March 1906."

The CHAIRMAN then presented the case of cutlery and cheque to Mr. Millar.

Mr. H. L. MILLAR, who was cordially cheered on rising to respond, said that when he received a letter from the Secretary saying that he desired to interview him for a few minutes, he thought it simply meant that a slight kindly expression for the still slighter duties performed, which had been more then amply acknowledged by invitations to many of the meetings and the Dinners as a guest of the Council, was all that was intended, and he was therefore very greatly surprised when the Secretary informed him of the presentation to be made. He certainly did not deserve the handsome gift of the members. The work he had had to perform was very slight, his duties consisting in preserving the funds which had been entrusted to him as Manager of the Union of London and Smiths Bank at Charing Cross, which was a sheer duty on his own part, and beyond endorsing a few cheques he had done little or nothing to deserve such kindness at their hands. On his appointment as Manager of the Bank, he laid down for himself the rule that, although the interests of the manager and the customers might appear to clash, in the main the interests of the

Bank lay in the interests of its customers; and that he had not altogether failed in trying to carry out that ideal was proved by the very kindly presentation which had been made that evening, by sundry other expressions of good feeling from the customers generally, and also by the presentation of a similar testimonial from his own Board, and from the congratulations and kind wishes of his fellow officers of the Bank. He thought, therefore, that he had been fairly successful, at all events in steering a middle course, by not seeking to extract the last shilling out of the customers, and, on the other hand, striving diligently to perform his duty to the Bank, which it had been his pleasure and privilege to do. He could not say he was retiring with pleasure. Considering that he was in his seventy-first year, and had served the Bank for forty-seven years, twenty years as Manager, no doubt it was time he did retire; he was sure it was, but still he felt deep regret at having to resign, and found it impossible to say how keenly he felt the parting with so many of his old friends. Although he had had nearly three thousand customers, he did not think he had left one who possessed any bad feeling towards him. Ever since he was a boy he had been deeply interested in all mechanical engineering matters, in fact his interest began with the attempt to lay the first cable across the Atlantic. He again desired to thank the members with all his heart for their great kindness to him that evening.

On the motion of Mr. VAUGHAN PENDRED, seconded by Professor ROBERT H. SMITH, it was unanimously resolved: "That Mr. FREDERICK WILLIAM ELLIS, having succeeded Mr. Harry Lee Millar, the late Treasurer, as Manager of the Charing Cross Branch of the Union of London and Smiths Bank, where the Institution Account is kept, be appointed Honorary Treasurer of the Institution of Mechanical Engineers."

The Discussion on Mr. Churchward's Paper on "Large Locomotive Boilers" was then resumed and concluded.

The Meeting terminated at Ten o'clock. The attendance was 159 Members and 99 Visitors.

LARGE LOCOMOTIVE BOILERS.

By Mr. GEORGE J. CHURCHWARD, *Member of Council*, of Swindon.

The modern locomotive problem is principally a question of boiler. The great increase in the size of boilers and in the pressures carried, which has taken place during the past few years, has necessitated the reconsideration of the principles of design which had been worked out and settled during many years' experience with comparatively small boilers carrying low pressures. The higher temperatures incidental to the higher pressures have required the provision of much more liberal water-spaces and better provision for circulation. Locomotive engineers have now apparently settled down to the use of one of two types of boiler for very large engines, the wide fire-box extending over the frames and wheels, and the long narrow box sloping up over the axles behind the main drivers.

In Great Britain the contracted loading-gauge prohibits the use of the wide fire-box type over wheels larger than 4 feet 6 inches diameter, so that it is not being used so generally as in America, where it has become practically universal. In America the great power of engines now employed renders the wide fire-box a necessity, but in Great Britain, where the coal burnt per mile is very much less, few boilers of this kind have been built. On the Great

Northern Railway Mr. Ivatt has provided his fine "Atlantic" class with wide fire-boxes, shown by Fig. 8, Plate 22, and they are undoubtedly very successful. On the North Eastern Railway Mr. Worsdell has also designed a wide box for the boiler of his new "Atlantic" type. Mr. Holden's boiler, on the heavy suburban engine for the Great Eastern Railway, is the largest of the type yet built in this country, Fig. 3, Plate 20. For the Great Western Railway Mr. Dean designed and built some goods engines with wide fire-boxes, shown by Fig. 11, Plate 24, and the author has since designed, but not yet built, a modified form of the same type to be carried over 4 feet 6 inches wheels, Fig. 10, Plate 23.

Much more experience has been gained with the wide box in America than in this country, and, so far as the author has been able to ascertain, it has been found there that the poorer coals in large quantities can be burnt with much greater facility and economy in this type than in the narrow pattern. This advantage is offset to some extent by the fact that, when standing, there is considerable waste in the wide grates as compared with the narrow, and this is, of course, serious when goods trains are kept standing about, as is often the case here. This disadvantage has been found on the Great Western Railway, but no doubt careful design and fitting of ashpans will keep this waste within bounds.

A much more serious trouble has been found in the leaking of tubes in these boilers. This seems to be quite general, and the Master Mechanics' Association has a committee specially investigating this question with a view to finding a remedy. All methods of tube-expanding have been tried, and also much wider spacing, even up to and over 1 inch, without curing the trouble. The reduction of the depth of the fire-box, in order to get a long box sloping over the trailing wheels of coupled engines, certainly increased the trouble from leakage of stays, but the alternative of a wide fire-box entails a much heavier engine for most of the types, and then apparently tube-trouble is increased. The wide fire-box evidently requires a higher standard of skill in the fireman, for unless the grate is kept well and evenly covered, there is a tendency to have an excess of air, reducing efficiency and increasing tube-trouble. With modern high pressures

the temperature of evaporation is so much increased that the provision for circulation, which was sufficient for the lower pressures formerly used, is doubtless insufficient. Boilers in which this provision has been made have shown a very marked reduction in tube- and stay-troubles.

It will be noticed that, in the illustrations to this Paper, very liberal areas have been given, and this is the general tendency in America.

It is probable that in the wider boxes the main mass of the fire being so much nearer the tube-plate has a bad effect on the tubes, as the intensity of the temperature at the tube-plate must necessarily be much increased. The extra width of box has enabled the tubes to be put much too near the sides of the barrel. When this is done, the water to feed up the spaces between the tubes near the back tube-plate has to be drawn almost entirely from the front of the barrel, and it is possible that in some cases the space left for this purpose is inadequate. It will probably be found that neglect of this consideration is the cause of three-fourths of the tube-trouble. In the boilers, Figs. 10, 14, and 26, an effort has been made to provide for this upward circulation near the back tube-plate by leaving a space between the tubes and barrel from top to bottom, of a sectional area equal to the combined area of the vertical spaces between the tubes at all points, with a balance to provide for the water coming back from the front of the barrel to feed the water-spaces of the fire-box. There is no doubt that the upward draught of water through the spaces between the tubes for, say, two feet from the back tube-plate is very strong indeed, and in all probability this is enough to prevent the necessary feed of water down the spaces of the fire-box unless ample area is given, so causing stay-trouble as well as tube-trouble.

By putting the clack-box for both injectors under the barrel, as shown in Figs. 10, 14, and 26, and providing an internal nozzle directing the feed back towards the fire-box, considerable assistance is probably given in feeding "solid" water back to the fire-box and hottest part of the tubes. It is generally supposed that the circulation in a locomotive boiler proceeds along the bottom of the

barrel from the front end down the fire-box front and up the sides and back of the fire-box. The author two or three years ago fitted a number of vanes in a boiler with spindles passing through lightly packed glands to the outside, with indicators to show the direction of the flow of water. Observations showed that the circulation was generally as stated above, but a little alteration of the firing had the effect of materially changing the direction of the currents and even of completely reversing them. Fig. 28, Plate 32, is submitted to enable the results of this experiment to be appreciated. The arrows show the different directions of the currents in the various experiments.

These experiments suggested the desirability of bringing a circulating pipe from the front of the barrel, bifurcated to each side of the fire-box at the foundation ring, but the consideration of possible danger from an outside pipe, open to the boiler, caused the experiments to be abandoned. The experiment has since been made in America, and it is reported that great reduction of trouble with side sheets resulted. The extended length of tubes seen in some designs of wide fire-box boilers is due to the use of 6-coupled wheels in front of the fire-box. Experience of long tubes appears to be quite satisfactory, and they certainly keep up the economical efficiency of the boiler when it is being forced to the limit of its capacity. In this respect the long tube fulfils the same function as that performed in boilers with shorter barrels by the Serve tube (which is favoured so much on the Continent).

The ratio of diameter to length of the tube undoubtedly has a most important bearing upon the steaming qualities of the boiler and upon the efficiency of the heat absorption. This is more particularly noticeable when the boilers are being worked to the limit of their capacity. If 2-inch tubes, say, are employed in barrels 11 to 12 feet long, when the boiler is being forced the length is not sufficient to absorb the heat from the amount of gases that a 2-inch tube will pass, and overheating and waste result. The amount of tube-leaking, which is experienced with modern wide boxes in America, has brought up again the idea that the spacing should be wider, say, 1 inch instead of $\frac{3}{4}$ inch, but, from the

investigations of a Master Mechanics' Committee, it appears that the wider spacing does not cure the trouble. It is clearly of no use to provide wider spaces for the upward current, unless equivalent area is provided for the downcoming water.

The gradual extension of the practice of making the top of the fire-box and casing flat instead of round is noticeable. On the Great Western Railway less trouble has been experienced with the flat top fire-box than with the round top, although no sling-stays of any kind are used. The flat top has the important advantage of increasing the area of the water line at the hottest part of the boiler, and so materially contributes to the reduction of foaming. This, combined with the coned connection to the barrel, has enabled the dome, always a source of weakness, to be entirely dispensed with and drier steam obtained. The author some years ago made an experiment to settle this much-disputed point. Two identical engines and boilers were taken, one boiler having a dome in the usual position on the barrel, the other having no dome, the steam being taken by a pipe from the top of the flat fire-box casing. The engine without the dome proved to be decidedly freer from priming than the other. The liberal dimension of 2 feet between the top of the fire-box and the inside of the casing no doubt contributed to this satisfactory result. The coned barrel connection, in addition to providing a greater area of water line, also gives a larger steam capacity, and, by the larger diameter being arranged to coincide with the line of the fire-box tube-plate, much more water-space at the sides of the tubes is possible. On consideration of the great intensity of temperature at the fire-box plate as compared with that at the smoke-box plate, the advantage of the arrangement is obvious.

There is really little to be said as to fire-box stays. The stay question is in very much the same position in which it has always been. For the present high pressures, copper is still being used below the fire-line with closer spacing down to $3\frac{1}{4}$ inches pitch. Bronze is often used above the fire, and the boilers of the De Glehn compounds are so fitted. In America Yorkshire iron is still used, and recently Professor Hibbard, experimenting there on some iron

TABLE 1 (*continued on opposite page*).

Fig. Plates 19–32.	Engine.	Type.	Cylinders.
1	Mallet Compound—Baltimore and Ohio	0–12–0 Articulated	20 32 } × 32
2	Lake Shore and Michigan Southern	2–6–2	$20\frac{1}{2}$ × 28
3	"Decapod"—Great Eastern	$\frac{0\text{–}10\text{–}0}{\text{T}}$	$18\frac{1}{2}$ × 24
4	Baldwin Compound—Atchison-Topeka and Santa Fé	2–10–2	19 32 } × 32
5	Cole 4 Cyl. Compound—New York Central and Hudson River	4–4–2	$15\frac{1}{2}$ 26 } × 26
6	Compound—Colorado and Southern	2–8–0	16 28 } × 32
7	Chicago and Alton	4–6–2	22 × 28
8	"Atlantic"—Great Northern	4–4–2	19 × 24
9	Baldwin 4 Cylinder Compound—Chicago, Burlington and Quincy	4–4–2	15 25 } × 26
10	Great Western	2–6–0	19 × 28
11	Do. Do.	4–6–0	20 × 24
12	North Eastern	4–4–2	20 × 28
13	Do. Do.	4–6–0	20 × 26
14	Great Western	4–4–2 4–6–0 2–8–0	18 × 30 18 × 30 18 × 30
15	New De Glehn Compound—Great Western	4–4–2	$14\frac{3}{16}$ $23\frac{5}{8}$ } × $25\frac{3}{16}$
16	"La France"—Great Western	4–4–2	$13\frac{3}{8}$ $22\frac{1}{16}$ } × $25\frac{3}{16}$
17	Chicago, Burlington and Quincy	—	—
18	Illinois Central	—	—
19	Canadian Pacific	2–6–2	20 × 26
20	Great Eastern	4–4–0 0–6–0	19 × 26 19 × 26
21	London and North Western	4–4–0	15 $20\frac{1}{2}$ } × 24
22	Midland	0–6–0	18 × 26
23	Compound—Midland	4–4–0	19 21 } × 26
24	North Eastern	4–4–0	19 × 26
25	"Cawdor"—Great Western	4–4–0	18 × 26
26	Great Western	4–4–0 4–4–0	18 × 30 18 × 26
27	Water tube—London and South Western	4–4–0	19 × 26
—	Do. Do.	4–6–0	4 (16 × 24)

(*concluded from opposite page*) TABLE 1.

Fig. Plates 19–32.	Coupled Wheels.	Weight. On Coupled Wheels.	Weight. Total of Engine.	Total Heating Surface.
	Diameter. ft. ins.	Tons. Cwts.	Tons. Cwts.	Square feet.
1	4 8	144 5	144 5	5,600
2	6 8	58 0	77 18	3,343
3	4 6	80 0	80 0	3,010
4	4 9	104 15	128 0	4,796
5	6 7	49 0	89 0	3,446
6	4 9	79 8	90 8	2,966
7	6 5	60 6	99 0	3,053
8	6 7½	36 0	65 10	2,500
9	6 6	41 8	87 14	3,217
10	4 7½	51 16	60 8	1,933
11	4 7½	47 4	59 10	1,518 Distributing 2,388 Absorbing (Serve Tubes)
12	6 10	39 0	72 0	2,456
13	6 8¼	34 17	67 2	1,769
14	6 8½	39 0	70 10	—
	6 8½	54 4	70 4	2,143
	4 7½	61 18	68 6	—
15	6 8½	39 0	73 6	1,617 Distributing 2,756 Absorbing (Serve Tubes)
16	6 8½	33 7	64 13	1,446 Distributing 2,456 Absorbing (Serve Tubes)
17	—	—	—	1,768
18	—	—	—	2,461
19	5 9	56 12	73 8	2,425
20	7 0	33 19	51 13½	1,630
	4 11	43 14	43 14	
21	7 0	37 0	57 12	1,508
22	5 3	43 16	43 16	1,403
23	7 0	38 3	58 9	1,598 outside plain tubes
24	6 10	35 5	51 14	1,413
25	6 8½	35 10	56 14	1,934
26	6 8½	34 6	55 6	1,818
	6 8½	36 2	55 6	
27	6 7	37 2	53 19	1,550
—	6 0	51 10	73 0	2,727

(Continued on opposite page.)

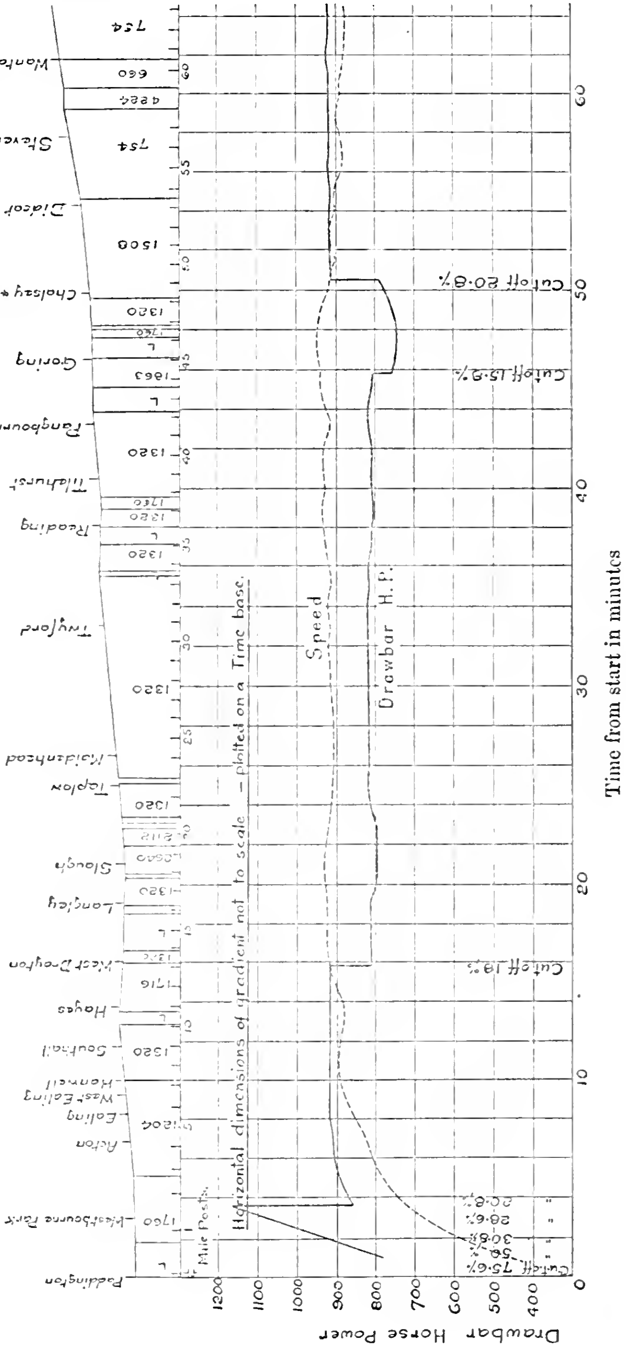


FIG. 31.—*Power and Speed Curves, for a train from Paddington to Bristol, Regulator full open throughout.*

Engine "Albion" No. 171. Class 4-6-0. Cyls. 18 ins. × 30 ins. Driving wheels 6 ft. 8½ ins.

Boiler, Plates 25, 33 and 34. Heating Surface 2,143 sq. ft.

Load, Thirteen 8-wheelers and a Dynamometer Car = 337 tons.

(One 8-wheeler slipped at Bath.)

(Concluded from opposite page.)

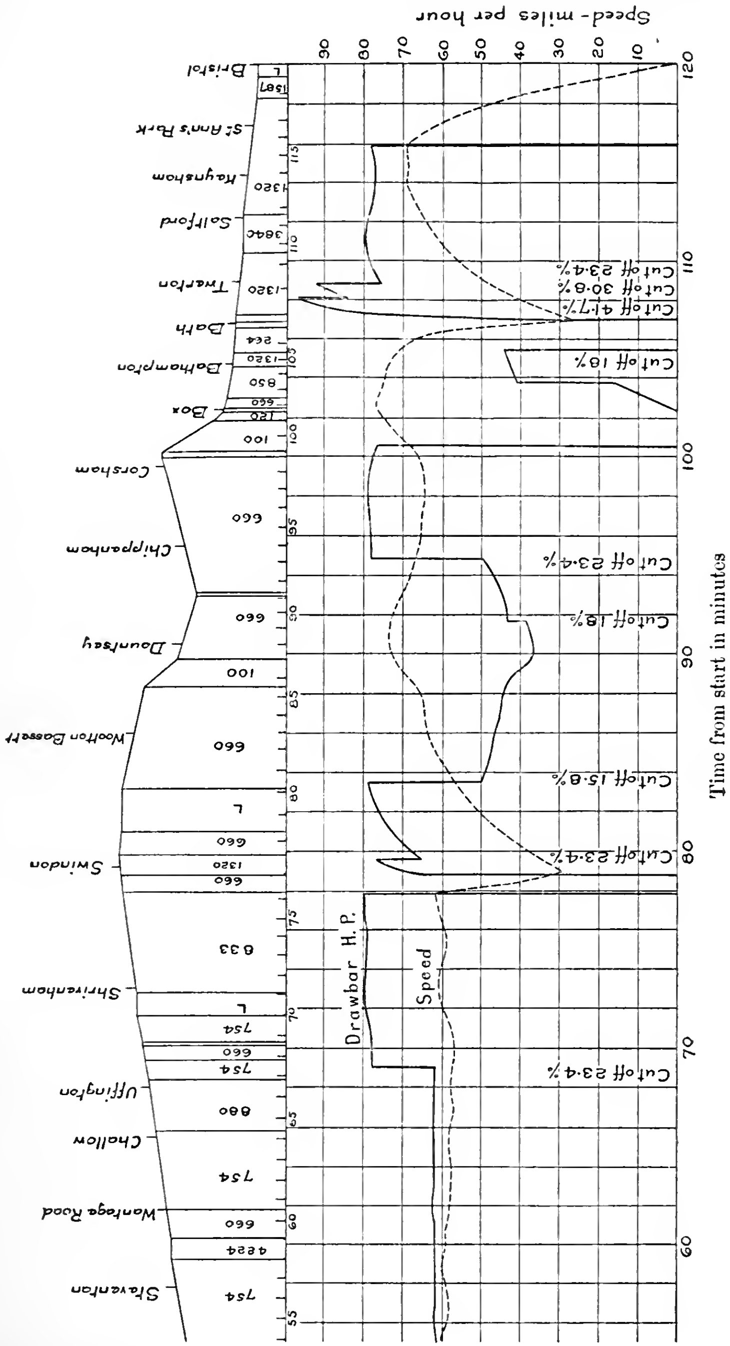


FIG. 31.—*(Continued from opposite page.)*

stays, arrived at the astonishing fact that the ductility of iron stays increased instead of diminished with the higher pressures now common. The author is using a few Taylor-iron stays experimentally with the view of ascertaining whether this material is more durable than copper, under the conditions brought about by the increased temperatures in modern boilers. Experiments are being made by many engineers with water-tubes in fire-boxes—notably by Mr. Drummond, of the London and South Western Railway, Fig. 27, Plate 32, who is so satisfied with the results that he is building this type entirely. Unfortunately, it is a necessity to have a deep fire-box in order to employ water-tubes effectively, or it is probable that many engineers would be following Mr. Drummond's example.

The employment of a superheater is having an extended trial in Germany and also in Canada. This affords the prospect of obtaining the same steam efficiency by the use of, say, 175 lbs. pressure, as by employing the pressures of, say, 200 lbs. to 225 lbs. This, no doubt, offers some prospect of success, and is attractive from the fact that the alternative of compounding necessitates the use of the higher pressures, and consequently presents no hope of relief from boiler troubles. The Great Western Railway are fitting one of their Standard No. 1 boilers, Fig. 14, Plate 25, with the Schmidt arrangement, with a view to see what advantage can be gained with the simple engine. Formerly the power of a locomotive was estimated largely from the capacity of its cylinders, and this led occasionally to the use of cylinders of such dimensions that the boilers provided were not capable of generating sufficient steam to enable them to be worked at their maximum economical power for any length of run. Today this is changed, and the first consideration is the capacity of the boiler.

Table 1 (pages 170 and 171) is presented showing the dimensions of cylinders and diameter of driving wheels used in connection with the various boilers illustrated, and an examination of the ratios will show how much more heating surface is now provided for a given area of cylinder than used to be considered necessary. The higher pressures now common have undoubtedly produced much

more efficient locomotives, both in respect of hauling power and coal consumption. This improvement has been very marked with every increment of pressure, right up to 227 lbs. carried by the De Glehn compounds. These have been most successful compounds, and the high pressure carried is no doubt an important factor. By employing 225 lbs. per square inch in the simple engine, and making the necessary improvements in the steam distribution, enabling higher cut-offs to be used, corresponding improvements in efficiency and economy of fuel have been obtained. Great increase in the draw-bar pulls at high speed has also resulted. Of course, the price for these improvements has to be paid in the matter of fire-box repairs and renewals, but it is probably better to submit to this expense than to employ the very much heavier and more costly machines which would be necessary to give the same hauling power at high speed. Plate 33 shows full particulars of the riveting, on barrel and fire-box butt-joints of the Standard No. 1 boiler, Fig. 14, Plate 25, and Fig. 30, Plate 34, on the Great Western Railway.

Fig. 31 (pages 172–173), shows the power and speed-curves for an engine of the 4–6–0 type on a run from Paddington to Bristol, the gradient diagram for which is also given. This engine carries the boiler shown on Fig. 14, Plate 25, and also on Plates 33 and 34, the pressure being 225 lbs. per square inch.

The author has to express his cordial thanks to the many engineers who have so kindly furnished him with the drawings of boilers, from which the diagrams accompanying this Paper are produced.

The Paper is illustrated by Plates 19 to 34, and 1 Fig. in the letterpress.

Discussion on Friday, 16th February 1906.

Mr. CHURCHWARD said the Paper was written some time ago, and, as an apology for the meagre character of some of the information, he might state that it was written mainly with the view of promoting a discussion and of eliciting probably more useful information than he had at the time of writing. The curves, Fig. 31 (pages 172 and 173), had been placed amongst the diagrams, as he thought it would be interesting for the members to see what actual horse-power was obtained from a boiler of any particular dimension given in the list. As would be seen, he had identified the boilers, so that the members might make such calculations on the subject as they might feel interested in doing. The ratio of the heating surface to the grate area would be seen in a number of examples to vary between very wide limits indeed, but he thought it was being more and more conceded now that the best ratio was the greatest possible number of square feet of heating surface to any given amount of grate. That seemed to be the rule on which a good many engineers were designing today, and so far as any observations he had been able to make were concerned, it was certainly the most successful way of going to work.

The tests that had been made at the St. Louis Exhibition by means of the splendid plant which the Pennsylvania Railroad Co. put down and worked were just being issued, and by the courtesy of Mr. Theodore Ely he had received a copy* within the last two or three days. He had not been able to go through it, and it would probably take a very considerable time to appreciate all the valuable information given, but he thought the members would be interested in hearing one or two conclusions that had been arrived at in connection with the boiler question after making the various tests. There was really a splendid amount of information in the book, and at the end was given a summary of conclusions. From the point of boiler performance the first conclusion arrived at was as follows :—" Contrary to a common assumption, the results show that

* Locomotive Tests and Exhibits at St. Louis, 1904.

when forced to maximum power, the large boilers delivered as much steam per unit area of heating surface as the small ones." The second conclusion was:—"At maximum power, a majority of the boilers tested delivered 12 or more lbs. of steam per square foot of heating surface per hour; two delivered more than 14 lbs.; and one, the second in point of size, delivered 16·3 lbs. These values, expressed in terms of boiler horse-power per square foot of heating surface, are 0·34, 0·40, and 0·47 respectively. The two boilers holding the first and second place with respect to weight of steam delivered per square foot of heating surface are those of passenger locomotives. The quality of steam delivered by the boilers of locomotives under constant conditions of operation is high, varying somewhat with different locomotives and with changes in the amount of power developed, between the limits 98·3 and 99 per cent." Therefore the old figure that had been accepted, namely, that a locomotive boiler of good design gave steam with not more than 1 per cent. of moisture, had been confirmed over a large number of very careful tests. Then, "The evaporative efficiency is generally maximum when the power delivered is least. Under conditions of maximum efficiency, most of the boilers tested evaporated between 10 and 12 lbs. of water per lb. of dry coal. The efficiency falls as the rate of evaporation increases. When the power developed is greatest, its value commonly lies between limits of 6 and 8 lbs. of water per lb. of dry coal." There was a good deal more which he would not weary the meeting by reading, but he would advise anyone interested in the subject to get a copy of such valuable tests, which were to his mind the best that had ever been made.

On the motion of the President, a hearty vote of thanks was accorded to the author for his Paper.

Mr. George Hughes noticed that the author commenced with an axiom, that the locomotive problem of today was a question of boilers, and the same remark applied to locomotive repairs and maintenance. Everybody who had been engaged in locomotive work knew that the greatest troubles and difficulties were associated

(Mr. George Hughes.)
with the repair and maintenance of the boiler. It was also an axiom that the capacity of a locomotive entirely depended upon its fire-box.

An experienced engineer, when consulted on a valve-gear for an engine with 16-inch cylinders, advised a boiler of sufficient capacity for 18-inch cylinders. The speaker had not the slightest doubt, in regard to repairs to locomotive boilers, that there were many gentlemen present who, during recent years, when repairs had become necessary on account of the increased duty demanded from locomotive boilers, together with the increased wear and tear brought to bear upon them by increased temperatures by reason of the higher pressures, had almost been alarmed—and he used the word advisedly—at the extent to which grooving had taken place above the foundation rings, at the shoulders of the throat-plates, and also in the radii of the back plates or the fire-hole door-plates. That, to a works manager, had been a most serious matter as he had extra repairs to do, and consequently expenses had gone up.

Another point was that the high pressures had had a very detrimental influence upon the impurities of the feed-water. That might not be exactly within the limits of the Paper, but he might be permitted to say that the composition of the feed-waters in the different parts of the country were such as to have a tremendous effect upon the question of boiler repairs. Some two years ago he accidentally came across a fact which had a very considerable importance on the investigation into the effect of impurities in feed-waters. On account of increased pitting, he had to condemn some boilers which were only 4½ to 5 years old, and as a result of the investigation he decided to line the barrels of some boilers with copper plates, others with best Low Moor iron, and others with lead; at the time he felt positive in favour of lining the boiler barrels with lead, because lead was one of the metals having the greatest acid-resisting qualities. The locomotive boilers with lead linings had been only in traffic a short period when the outdoor manager came to him with some of the glass water-gauge tubes covered inside with a cloudy white substance. These gauge-glasses were taken to the chemist, who scraped sufficient off for a

qualitative analysis, and the substance was found to consist of lead carbonate. Then he remembered the old Dutch method of producing lead carbonate. In consequence of that incident he formulated the theory, which he eventually proved, that the carbonates deposited at the forward end of the boiler were acted upon by the higher temperatures, and that there was a system of action and re-action continually going on between the substances, liberating carbonic acid, which, in its nascent state, attacked the boiler very considerably. Probably that was somewhat outside the question of the Paper, but he thought it would be very interesting to the members.

The experience on the Lancashire and Yorkshire Railway with large boilers commenced in the early part of the year 1899, and he would take the liberty of reading some figures in regard to their designs. Mr. Aspinall, at the beginning of that year, introduced his ten-wheeled passenger engine of the type 4–4–2. There were forty of them. The cylinders were 19 inches by 26 inches, coupled wheels 7 feet 3 inches diameter, 35 tons on coupled wheels, 58 tons 15 cwt. total weight, and 2,052 square feet of heating surface. It would be gathered from those figures that they were large boilers. These were followed by seventy-nine coal engines of the 0–8–0 type, 20 inches by 26 inches cylinders, 4 feet 6 inches wheels, 53 tons 15 cwt. on the coupled wheels, with a total weight of 53 tons 15 cwt., and practically the same heating surface as the large passenger engine, namely, 2,152 square feet. They were followed by twenty-one engines with about the same heating surface, but instead of having rectangular fire-boxes a corrugated flue was inserted, Fig. 33 (page 180). That corrugated flue was 9 feet 11½ inches long, the interior diameter being 4 feet 9 inches, and the exterior diameter 5 feet 1½ inches. The grate area was 26 square feet. As far as the corrugated boxes were concerned for locomotives in this country, it was a somewhat unique experiment, and at the very beginning it was seen that experience in that direction would have to be bought; and, knowing this, some of the boilers were fitted with longitudinal stays right from the back to the front, some with gusset-stays, and some with stays from the back-end gusset-stays to the forward end of the corrugated box. The majority of the engines

(Mr. George Hughes.)

FIG. 32.

Particulars see opposite page.

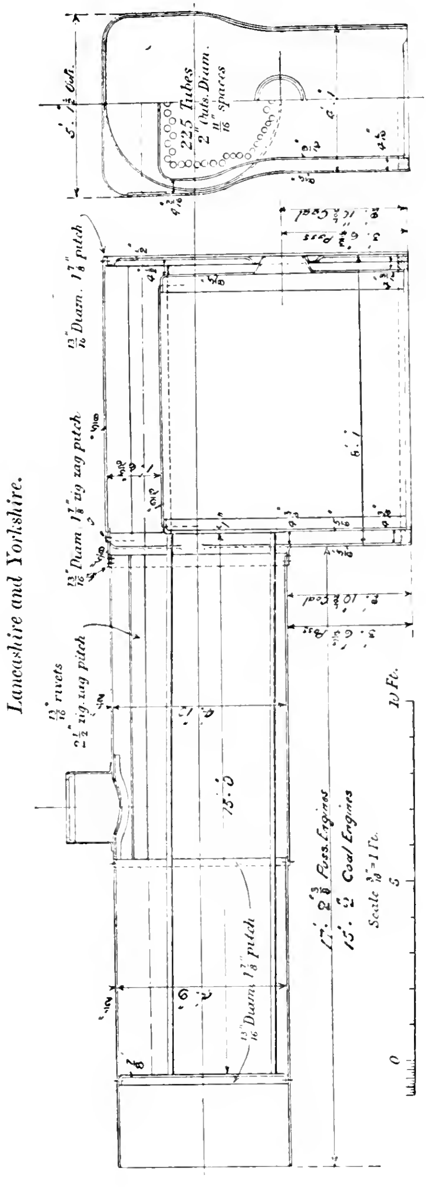


FIG. 33.

Particulars see opposite page.

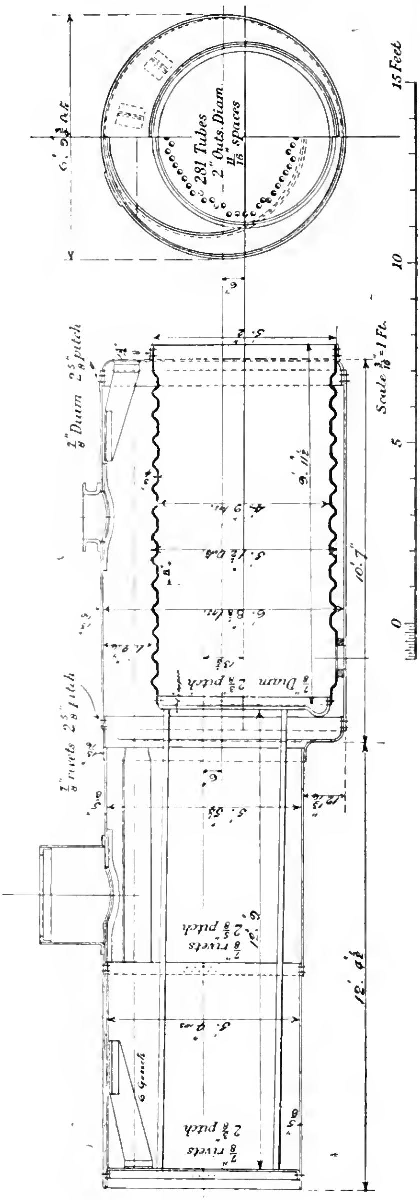


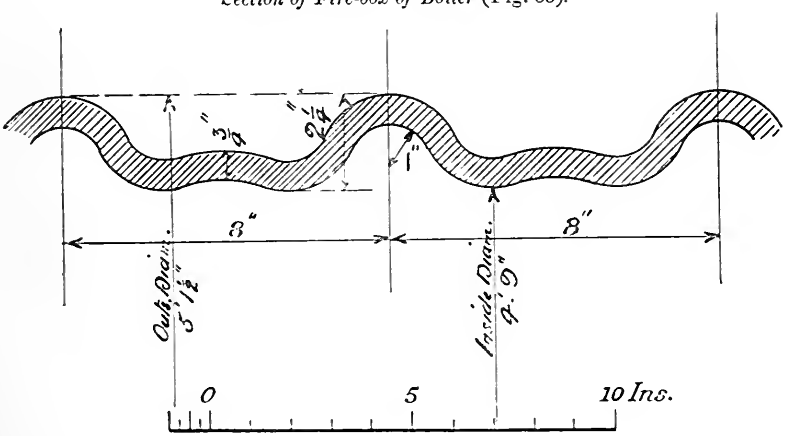
FIG. 32.—*Boiler and Fire-box Shell (L. and Y.) for* 10-*Wheeled Bogie Passenger and* 8-*Wheeled Coal Engines.*
Boiler Pressure 180 *lbs.*

	10-Wheeled Passenger Engine.	8-Wheeled Coal Engine.
	square feet.	square feet.
Tube Heating Surface .	1,767	1,767
Fire-box Heating Surface .	161	147
Total . .	1,928	1,914
Grate Area . . .	23	23
Flue Area . . .	3·75	3·75
Steam Space . . .	75 cu. ft.	76 cu. ft.

FIG. 33.—*Boiler with Corrugated Steel Fire-box (L. and Y.) for* 8-*Wheeled Coal Engines.*
Boiler Pressure 180 *lbs.*

	square feet.
Tube Heating Surface . . .	1,882
Fire-box Heating Surface . .	125
Total . . .	2,007
Grate area	26
Flue area	4·67
Steam space	52 cu. ft.

Section of Fire-box of Boiler (Fig. 33).



(Mr. George Hughes.)

were fitted with $\frac{5}{8}$-inch steel tube-plates, but two of the engines were fitted with copper tube-plates. When the engines went into traffic there were various troubles, but during the period of three years those had been overcome. One of the greatest difficulties was the leakage of tubes, which was absolutely confined to the engines with steel tube-plates; the two engines with copper tube-plates did not leak at all. Consequently the steel tube-plates had been gradually changed to copper tube-plates.

There was another difficulty anticipated from marine experience, namely, that probably some of those boxes would come down, and consequently a 200-ton jack was purchased. He might state that at the present time the deflection in those corrugated boxes did not exceed in any one particular corrugation 0·97 inch and a minimum of 0·06 inch. There was one case—engine 157—in which the fire-box crown came down about 1·38 inch, but by the use of the 200-ton jack it was repaired at a very small cost. The initial cost of the boilers with steel corrugated flues was considerably less than those with the rectangular copper fire-boxes.

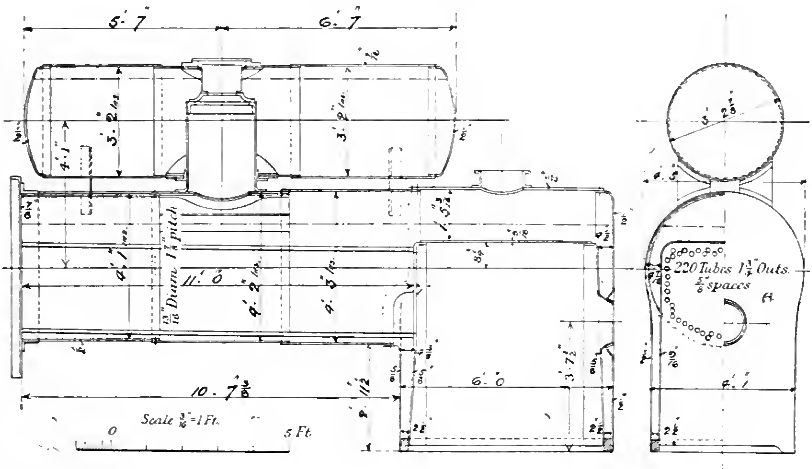
With regard to the general question of maintenance, he could not give figures because money had had to be spent on getting over difficulties of untried design, but it was an absolute fact that the engines with the corrugated boxes had taken their turn in their respective links with the ordinary engines, and, when all factors were brought into line, he had no doubt that those with corrugated boxes would be somewhat more economical.

A short time ago it was necessary to give Mr. Aspinall's design of radial passenger tank-engine a boiler of greater capacity. It was not advisable to alter the design of the engine, and by adopting the Belpaire type, Fig. 32 (page 180), they were able to get into that engine, without altering a single tank angle-iron, a boiler with about the same heating surface, but more water space round the fire-box, 20 per cent. more water space in the boiler and 40 per cent. more steam space.

Another instance of increasing boiler capacity: six of Mr. Aspinall's ordinary standard tank-engines were fitted with the Halpin system of storage heating, Fig. 34 (page 183), and Fig. 35,

Plate 34. That system, no doubt, most engineers were aware of. The dimensions of the tank placed on the locomotive was 12 feet 2 inches long, and 3 feet 2 inches internal diameter, and it would hold 420 gallons of water. Taking one engine with another and

FIG. 34.—*Boiler and Fire-box Shell (L. and Y.) fitted with Thermal Storage Tank. Boiler Pressure* 180 *lbs.*



	square feet.
Tube Heating Surface . . .	1,103
Fire-box Heating Surface . .	107·68
Total . . .	1,210·68
Grate area	18·75
Flue area	2·7
Steam space	43 cu. ft.
Capacity of storage tank . .	420 gals.

one man with another—because the human element could not be eliminated—there was a saving of about 4 per cent. That was not very much, but taking individual cases, certain trips where the nature of the road and stopping at stations was favourable to the system, as much as 12 per cent. had been obtained.

(Mr. George Hughes.)

The author in concluding his remarks had referred to the Report just issued by the Pennsylvania Railroad Co. of the tests of eight locomotives at the Louisiana Purchase Exposition at St. Louis in 1904. It had been his privilege also to receive a copy, and it was a most remarkable document. The experiments carried out on those eight engines embraced every possible conceivable point. He had not had time to read it absolutely through from cover to cover, but there were two or three facts he had noticed. One of them was that two of the eight locomotives had copper fire-boxes, but no economy or capacity could be traced to those copper fire-boxes. The same remark applied to one of the locomotives fitted with Serve tubes. Another remark rather confirmed something he had thought about a great deal, that compound locomotives were more efficient at slow speeds than high speeds, therefore raising the question: "Why in this country were passenger engines compounded instead of goods engines?"

The author had spoken of superheating. It had been very successful on the Continent and in America. Mr. Vaughan, of the Canadian Pacific Railroad, told him (the speaker) when he was there last June that there was infinitely more in superheating than there was in compounding. The only drawback to superheating was the necessity for using piston-valves, but it was only fair to record that superheating prevented the presence of water in cylinders, which had always been so detrimental to piston-valves in non-superheated engines.

Mr. James Stirling said he had come to the meeting quite unprepared to speak, and he felt somewhat outside the official world. Of course he was rather old-fashioned, as it was some years since he retired, at a date when large boilers were only beginning to be thought of in this country. Nowadays he was humbly of opinion that locomotive engineers were going rather far with their large boilers, that they were making more steam than they could use. It would be noticed on many of the principal railways that, where big engines were drawing big trains the boilers were blowing off at least 10 to 15 per cent. of their steam. This state of matters he thought could hardly be called economical.

With regard to the large grate area now the fashion, he could hardly help thinking that this had a great deal to do with the leakage of tubes and stays referred to by the author. In his own day, with the smaller area of fire-grate, it was found difficult to maintain a level fire and to prevent blow-holes in the fuel, these blow-holes almost invariably starting tube leakage. If that was the case with the small fire-boxes, it must be much more so with the large ones now so common, and the difficulty of maintaining a level fire was very much enhanced and blow-holes were much more likely to occur, with the consequent leaking of tubes and stays.

With regard to feed-water, he believed he had fed water into locomotive boilers in almost every way possible to think of. He had delivered it in the smoke-box tube-plate, sending it straight back to the fire-box, under the impression, as was natural, that the ebullition being most violent at the top of the fire-box and in the immediate neighbourhood of the tube-plate, that the current of water must necessarily flow to the smoke-box end and come back to the fire-box under the tubes; the results were very satisfactory as to steaming. The next thing was to deliver the water over the top of the fire-box in front of the tube-plate, but that only created fouling of the tubes where they could not be got at in washing out. He then fed the water in at either side of the fire-box, with the result that all the stays began to leak forthwith. The next and the last thing was to feed the water in the old-fashioned place, namely, in the side of the first plate from the smoke-box of the boiler, and he there had a command of the fouling, and could get the hose-nozzle at it on washing-out days and clear it away; in that way he managed to keep his boilers fairly clean. Those dealing with locomotive boilers knew that the moment the water reached the heat it immediately precipitated any lime or deleterious matter that might be in it.

With regard to the construction of boilers at the present day, he was not going to enter into that question. Many of the very interesting diagrams the author had shown were novel in shape and expensive in construction; they might be good, but they were certainly not "bonnie," to use a Scotch expression. He was very

(Mr. James Stirling.)

pleased to find that the author had discovered in the early part of the twentieth century that it was possible to get dry steam from a locomotive boiler, without the use of a dome. The large boilers were limited to a certain extent by the height of overhead bridges in this country, and that affected any increase of height on the top of the boilers such as domes, and rendered them of no use in the matter of dry steam. The author's distinguished predecessor, Sir Daniel Gooch, many years ago introduced engines on the Great Western Railway with internal steam-pipes, and Messrs. R. and W. Hawthorn and Co., of Newcastle, delivered to the Glasgow and South Western Railway, where he, Mr. Stirling, served his apprenticeship, little four-wheeled goods engines with internal steam-pipes, with slots instead of the drill-holes he used himself, and these engines were the cleanest running engines in the service. In those days the steam space between the crown of the box and the interior of the boiler barrel was 15 inches—that was his distance between the crown and the barrel when he began designing. After he had charge, he began to lower the crown of the box with the view to increasing the dryness of the steam, and continued lowering the fire-box inch by inch, carefully and with the desire not to overstep the mark, and latterly he got down to 24 inches, and the Great Western Railway had followed his example. He obtained very satisfactory results, and was even able to dispense with heating surface in the tubes, getting more steam in that way than he obtained with a greater number of tubes.

Mr. C. E. CARDEW said he had only recently returned to England and was not very well up in the question of large boilers, as his practice had been with rather small boilers on the metre-gauge railways in India, where heavy engines were not generally used, although they were increasing in size from what they were a few years ago. He had come to the meeting with the view of hearing what the home engineers had to say about large boilers, rather than of giving his own opinions about them. He had listened with great interest to the Paper and thought there was little to find fault with in it. There were a few points that might be

further elucidated, and with the permission of the President he would run through them. The author said (page 166), "Much more experience has been gained with the wide box in America than in this country, and so far as the author has been able to ascertain, it has been found there that the poorer coals in large quantities can be burnt with much greater facility and economy in this type than in the narrow pattern." He had a case very much in point, in which his experience did not agree with that. In Burma there was some poor stuff called coal, a sort of material between German brown coal and lignite, and it was a question of building a special boiler to burn it. A well-known American locomotive building firm were called in to see what they could advise, and they gave a special design of Wootten fire-box with practically no other departure from the ordinary type of boiler. This firm had previously designed a similar fire-box for some of the Japanese railways, and its performance had been most successful with a similar kind of coal. In order to make certain of the firm having every kind of facility for making a proper design, he sent it a quarter of a ton of coal which it was desired to burn, namely an eighth of a ton of the worst of its sort and an eighth of a ton of the best. The firm was confident that the design submitted would be very effective. The boiler was made and set to work, but it failed to burn that particular coal satisfactorily. He had never been able to form an opinion of the reason for this. The boiler would not steam with it; but it was thought that probably some alterations were needed in the draught. Several alterations were accordingly made, but with no satisfactory result. The engine fitted with this boiler was put into running with a number of others working the same trains over the same road, with the same enginemen, who were changed about occasionally, so as to get a fair average. The conclusion arrived at was that the old narrow fire-box burnt the lignite quite as well, if not better, than the broad Wootten fire-box, though neither of them steamed satisfactorily with that coal. It was slaves' work for the firemen, and it was only with the greatest care that the traffic was worked without delay during the long experiments that were made with that coal.

(Mr. C. E. Cardew.)

To complete those experiments, he thought he would try one thing more, so he put that boiler on good Bengal coal—coal as good as English north-country coal—and it at once showed a remarkable efficiency. It not only steamed better than the boilers with narrow fire-boxes, but month by month it came out at the top of the list for lowest consumption. Apparently therefore, though a wide fire-box might do better than a narrow fire-box on good coal, yet it would not necessarily do better than a narrow one on certain kinds of bad coal. The reason for this he could not explain, as he had been quite unable to ascertain it, and he did not think it likely that the question would ever be definitely settled.

On the same page the author remarked that much more serious trouble had been found with the leakage of tubes in those boilers, and then he went on to state American experience, and that the Master Mechanics' Association had a committee on the subject. He did not exactly say what the trouble was so far as his own boilers were concerned, or what he proposed to do in their case. But he went off at a tangent in giving his remarks upon American experience and what Americans were doing to overcome the difficulties. It would be desirable to learn more details from the author as to what extent of leakage had occurred in his boilers, and how he proposed to overcome it. In the discussion, Mr. Hughes had stated his experience to be that the leaking only took place where steel tube-plates were used. He himself had had experience with both steel and copper tube-plates, and he would not like to say that the steel plate leaked more than the copper plate, but he had certainly found that steel tubes in copper plates occasionally gave considerable trouble, while brass and steel tubes in steel plates did not usually give the same trouble.

On page 167 the author stated that he was now directing his feed-water backwards towards the fire-box, in order evidently to give a quicker and better water-supply to the place where there was the greatest heat. That confirmed his own opinion of what ought to have been done long ago. For many years it had been a sort of dogma to get the water into the boiler without giving it a chance of going near the fire-box, as it was looked upon as a dreadful thing

to let cold water go down towards the fire-box. He had even seen a rather curious arrangement put into boilers in the shape of bent delivery-pipes, in order to deflect the water towards the front end. Those bent pipes after a short time became built-up solid with scale, which caused no end of work to remove it, ending with their having to be cut out altogether.

On page 169 he noticed that the author stated that with a coned barrel connection the boiler was said to give a greater area of water-line, etc. From this it was not understood whether the author meant that this was his own experience, or that such was the intention of the original designer. If the latter, he thought he must be mistaken. There was a Paper read by a member of the Institution in 1887, Mr. F. R. F. Brown, the late Superintendent of Motive Power of the Canadian Pacific Railway, on "The Construction of Canadian Locomotives," * in which it was stated clearly that the coned barrel was designed originally to prevent the water in the fire-box from being shot ahead into the barrel of the boiler when the engine plunged into a snow-drift. By that arrangement the water was kept approximately where it was most wanted, namely, over the fire-box.

He was interested to read the author's remarks (page 174) with regard to experimenting with Taylor-iron stays. He had often wondered why Yorkshire iron had not been used in this country much more than it had been. His own impression was that it was thought to be too hard for riveting into copper fire-boxes, and probably that was the reason for its non-use. He hardly thought it necessary however at this period to make experiments as to whether Taylor-iron, or any other good Yorkshire-iron, was fit for water-space stays. The Americans and Canadians, with their great experience gained on some 300,000 miles of railway, had surely settled that question, without the need of making experiments over again. Then there were thousands of portable and semi-portable boilers built in this country by all the most reputable builders, in which the fire-boxes were stayed with nothing but Yorkshire iron.

* Proceedings 1887, page 186.

(Mr. C. E. Cardew.)

With regard to Yorkshire-iron stays becoming brittle, and the author's surprise at finding he could break them off with a hammer, it had been known generally for some time that that could be done. Within the last two months he himself had been in Canada, and in going through the Angus workshops of the Canadian Pacific Railway, in Montreal, he saw men breaking the stays out of a condemned fire-box in the very way the author described. A man with a 14-lb. hammer simply knocked the stays off one after the other, breaking them quite easily. He enquired how long they had been in running, and was told that this fire-box was just twelve years old. He was also told that if the stays were tested, the iron would be found to be perfectly ductile, and of its full original strength. When going through the Angus shops he also saw what seemed to be a much larger boiler than the one illustrated in the Paper. The one shown on Fig. 19, Plate 28, was, he fancied, though he was not quite sure, a freight-engine boiler, but the one he saw was a new passenger-engine boiler, that had been just turned out. It was in type a very close approximation to that shown as the Chicago, Burlington and Quincy, Fig. 9, Plate 23, with the peculiar set-back of the front leg of the fire-box.

Mr. Hughes had said how very serious grooving had become. In India, however, thirty years ago grooving was much worse than it was today. Matters had improved a great deal since then, so that they were now not troubled with the excessive grooving of fire-boxes above the foundation-rings to anything like the extent they were thirty years ago. When he was on the Râjputâna Railway, the water there was probably one of the worst in the world; so far as he could recollect, it had something like 20 grains to the gallon of sulphate of magnesium, the very worst thing that could be found in locomotive feed-water. Mr. Hughes had also said that he had been making experiments by lining boilers to prevent pitting. He himself made that identical experiment on a pretty large scale in the Ajmêr workshops of the Râjputâna Railway in the year 1880, when he was works manager there. He, however, did not line the boilers with sheet-lead; he lined them with a coating of red-lead putty, and over that placed good sheet-iron. The sheet of

iron was put over the red-lead putty merely to keep the putty in its place, and was held down to the belly of the boiler with studs. Those boilers, to his certain knowledge, ran for two years, and then came in for examination with the red-lead putty perfectly intact and the sheet of iron over it none the worse, while of course the boiler barrel had been saved from pitting. He left the railway soon after, and had never since been in a part of the country where the water was so bad, so that he had never bothered about making the experiment again, but he was quite positive that that was a form of protection which could be easily applied without any danger to the boiler, and without the mischief of which Mr. Hughes had spoken. The boiler pressure in those days was 140 lbs. per square inch.

Mr. Hughes had also narrated the very interesting experiment of introducing corrugated fire-boxes on the Lancashire and Yorkshire Railway. It would have been historically interesting if he had explained in what way those fire-boxes differed from those of Mr. Cornelius Vanderbilt, the well-known American engineer, who introduced the same thing in America some years before it was thought of in England. He had not been able to keep track of the results of those experiments, but it would be certainly interesting to know in what respect the two fire-boxes differed, and which of them had behaved the better.

Mr. Stirling had rightly observed (page 185) that half the difficulty of keeping tubes from leaking and other mischief of that sort could be got over by getting the dirt out of the boilers. In that connection he should like to take the opportunity of bringing before the Institution an American invention that he had been the first locomotive engineer to take up, but in which he had no financial or other personal interests, namely, the Hornish mechanical boiler-cleaner, Figs. 36 to 38 (page 192). When it was first brought to his notice he rather suspected it was an American freak, but deciding to give it a chance he wrote to the inventor, who had patented it all over the world, asking for permission to give it a trial in his (Mr. Cardew's) own way. Permission was accorded to him to do what he liked, and he put one of the Hornish mechanical boiler-cleaners into a boiler. The cleaner consisted of a transverse trough just about the

(Mr. C. E. Cardew.)

Mechanical Boiler-Cleaner (Hornish), as used on Burma Railways.

FIG. 36.—*General Arrangement.*

The arrows show direction of current circulating in boiler, as experimentally proved by a model boiler made of glass.

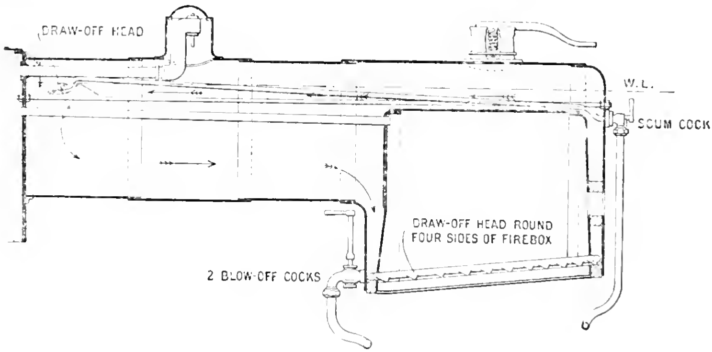


FIG. 37.—*Details of Skimmer.*

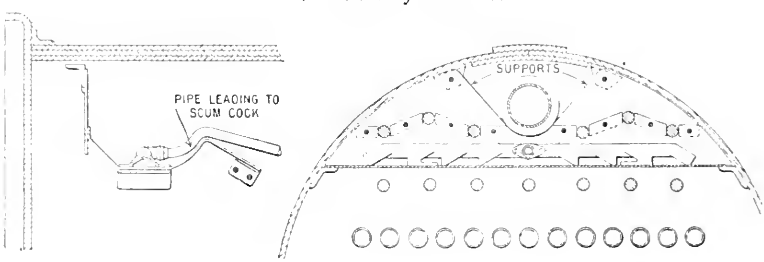
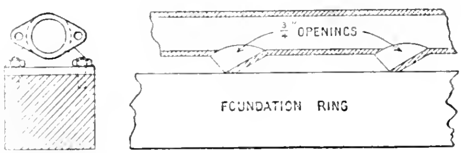


FIG. 38.
Detail of Draw-off Head over Foundation Ring.



water-line, Figs. 36 and 37, at the front end of the boiler, up against the smoke-box tube-plate, and in that trough there was a pipe with little suckers in its bottom. The pipe was connected by a pipe running through the back of the fire-box to the ordinary scum-cock. That trough caught a very large proportion of all the dirt deposited in the boiler, and by using the scum-cock in the ordinary way, about once every hour, the trough or catchment was cleared of all the sediment caught in it. Anything the trough did not catch went down the front tube-plate and along the belly of the boiler into the water-legs, where there were similar pipes with similar suckers lying on the top of the foundation-ring, Fig. 38, and simply studded down here and there to keep them steady. Those pipes were connected with two or more draw-off cocks of any ordinary good pattern, which were only used once a day after the engine had done its work, and while it was over the pit. The engineman then turned the cocks on, and blew out the whole of the dirt that had accumulated in the legs. He had imagined that the whole thing would very soon get choked up and become useless. He therefore gave an order that the engine to which it was fitted should be allowed to run 2,000 miles without a wash-out, and at that time that particular class of engine was running 850 miles for each wash-out. After running 2,000 miles it was examined, but no dirt was found. It was then turned out again for a run of 5,000 miles, and still no dirt was found. Then it was run for 10,000 miles, with the same result—absolutely no dirt. Then he ordered it to run 15,000 miles. After 14,000 it had to come into the shop for another cause, and it was found there was not enough dirt in the boiler to fill a pint pot. He carried on that experiment for three years, and then obtained the sanction of the directors of his company to fit all the company's boilers with the cleaner, or at least all the new boilers, while the old engines were being fitted at the rate of twenty a year. If there were any real trouble in getting rid of dirt in the large boilers, he strongly advised locomotive engineers to give the Hornish boiler-cleaner a trial.

Mr. H. C. KING, as the Works Manager under Mr. Churchward, was able to state that the designs illustrated in the Paper, with the

(Mr. H. C. King.)
increased water surface, the conical barrel, and the improved area through which the water could very freely circulate, through the sides and back plates of the fire-box, had produced for his company, whatever that pattern may have produced elsewhere, nothing but unqualified satisfaction. He could therefore state with the use of the higher pressures, the steady rise from 150 lbs. to 165 lbs., then to 180 lbs., and now 200 lbs., with 225 lbs. as a limit, had not produced that measure of increased difficulty which some people had anticipated would vary as the arithmetical ratio of the pressure. Of course there were difficulties—no one using locomotive boilers was free from them—but there were no special difficulties incidental to the higher pressures. He was not going to say that that measure of satisfaction had been produced without constant and unremitting care on the part of all those in the boiler shop and in charge of the construction; everybody was aware that boilers were being built from which great things were expected, and he could say truthfully that the difficulties had not been proportional to the increased pressure.

The leakage of stays and tubes was an international matter, and those who were in Washington knew that the subject engaged the attention of the Congress for no small portion of their deliberations. It was not a question between one metal and another, as to the stay resisting the stress between the outer wrapper and the copper fire-box, but it was a question purely of the capacity of those metals to resist the erosion of the heated gases passing over the heads. The stays themselves were perfect when the heads had gone. That was the one great difficulty about the stay as he knew it. In that connection, although they had used the whole series of the bronzes, nothing had been found so satisfactory as copper.

With regard to the apparent brittleness of Taylor-iron after it had endured the stress and strain in a locomotive fire-box, he had also seen, in America, Taylor-iron stays and iron stays reputed to be Taylor-iron—and he believed there was a local firm of that name—and he also saw some of the finest product of the American iron works, all of which could be treated in a precisely similar way. He thought he knocked about fourteen of them off, and he did not

remember more than one that required a second stroke of a very light hand-hammer.

Tubes were another matter. The Great Western Railway for the last four or five years had found the consumption of ferrules steadily decreasing, and the consumption had decreased because the need of them had ceased to exist. He knew that he was addressing many who thought that a tube could not go out properly secured to a tube-plate without a ferrule being driven in in addition, but their boilers went out free from ferrules, and very often the life of that set of tubes was finished without one being inserted. Perhaps his excuse for speaking at all that evening might be found in the remark that, contrary to the usual practice of those who used the old-fashioned Dudgeon expander with the largest diameter of the cone upwards, it had been their practice to supply their men with expanders the largest diameter of which was just within the water space on the inside of the tube-plate, and by setting up the expansion on that line they had found very nearly an immunity from tube troubles. The intelligent man asked when the tubes were leaking, and if it was found the leaking was at 80 lbs. of steam when the boiler was being fired up, and was non-existent when the working pressure was attained and the engine was on the road, he could disabuse his mind of leaking tubes on service.

Discussion on 16th March 1906.

MR. GEORGE E. JONES ventured to think that, with high pressures and consequently high temperatures and long boilers, it was of some importance that both the shell and the contents, that is, the tubes and fire-box, should be of the same description of material, and should

(Mr. George E. Jones.)

expand at the same rate. The difference of expansion between the shell made of steel and brass tubes and a copper fire-box was, in his opinion, a not inconsiderable factor in causing destruction of copper fire-box tube-plates, and in the first stage, leaky tube troubles. That difference had to be accommodated, and he was of opinion that it put the copper fire-box tube-plate and the joints of the tubes in it under strain. The longer the boilers and the higher the temperatures, the greater that effect would be.

Mr. DRUITT HALPIN said that Mr. Hughes, at the previous meeting, referred (page 179) to the corrugated boxes which were being used in the engines on the Lancashire and Yorkshire Railway for the purpose of helping them to get over the troubles connected with high pressures and high temperatures. As far as he understood Mr. Hughes, he did not in any way claim what he was doing as a novelty, but merely gave it as an instance of modern successful practice. In continuing the discussion Mr. Cardew also referred to the subject, and seemed to claim priority for what Mr. Vanderbilt had been doing with corrugated boxes in the United States. He therefore desired to show some slides giving particulars of an apparatus of a very peculiar form which was worked on the Continent even earlier than the one referred to.

The whole locomotive shown in Fig. 39 (page 197)* was built from the designs of Mr. Lentz, who was for many years the engineer of the Hohenzollern Works, near Düsseldorf. The box was horizontal in what one might call the smoke-box part of it. In the furnace part it was dropped down, and the casing was dropped down also. The casing tapered at the other end towards the smoke-box.

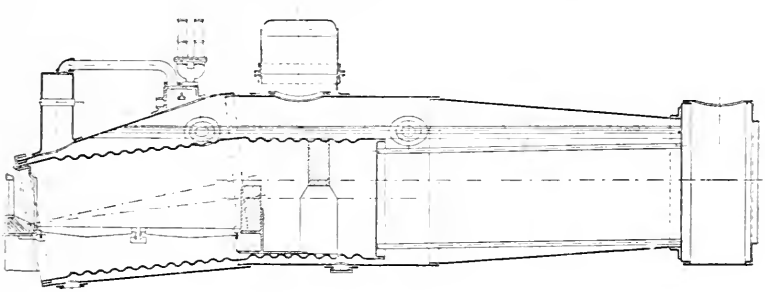
In the course of the discussion in regard to large boilers, Mr. Stirling said that both the Great Western boilers and the American boilers shown in the Paper were not "bonnie" to look at. He quite agreed with that statement. Any of the members who had lately been to the South Kensington Museum would see the great resemblance between the locomotive shown in Fig. 39 and the

* "Zeitschrift des Vereines Deutscher Ingenieure," 1895, Fig. 11, page 251.

beautiful replica of the skeleton of the diplodocus (with which Mr. Carnegie had endowed the nation) which tapered at both ends. One of the troubles experienced with the series of boilers shown was that one of them blew up the passenger station at Bonn with disastrous results. The government thereupon discontinued the use of the other boilers. He merely gave the illustration to show that there was such an apparatus in existence before Mr. Vanderbilt's.

Another attempt had been made to get over the trouble in Hungary by Mr. Verderber, one of the engineers of the Hungarian State Railway. He apparently thought the easiest way to get over the trouble of fire-boxes was to abolish the box altogether, and some

Fig. 39.—*German Express Locomotive* (Lentz), 1894.



very good results were obtained. He started with the arrangement shown in Fig. 40 (page 198). He simply took an ordinary boiler, and left it as it was except that round the crown, the sides, and the back he put fire-tiles at a distance of 3 or 4 inches, fastened on very ingeniously, so as to cut off the heating effect of the furnace as far as the box was concerned. In order to accentuate that precaution, air channels were placed at the side, and the air was taken up by the front side channel and down by the back channel on the side, and then into the ash-pit, and the same on the other side, so that very good isolation of heat was obtained; this treatment practically did not harm the boiler, as it did not change it in any way. He worked it, and found that he obtained as much steam and burnt as

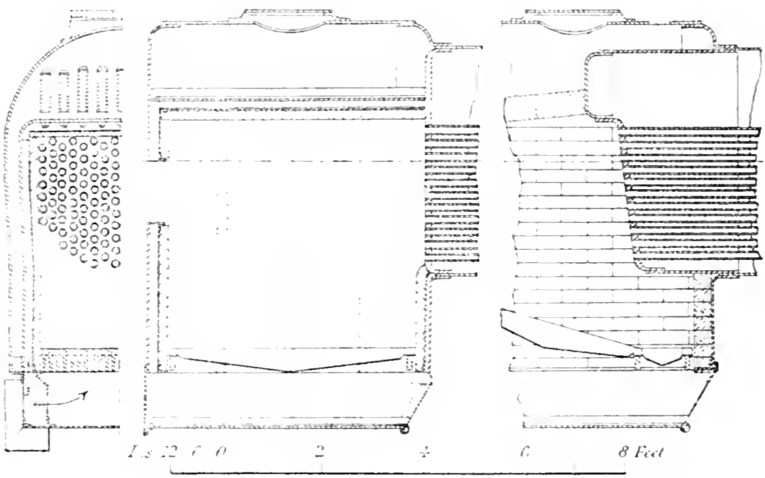
(Mr. Druitt Halpin.)
little coal as before. Having assured himself of that, he went a step further, and the next apparatus he tried was that shown in Fig. 41. The copper box was cut out bodily, and a plain tube-plate was put in at the end of the barrel, the tubes running through in the ordinary way towards the smoke-box end. The firebrick casing extended all round the box. Mr. Verderber steamed with that engine for some little time, and then found that the leakage in

Hungarian State Railways Locomotive Boilers (Verderber).

FIG. 40. *Adapted to old fire-box with water-space.*

FIG. 41. *Adapted to old fire-box without water-space.*

FIG. 42 *Special Design.*



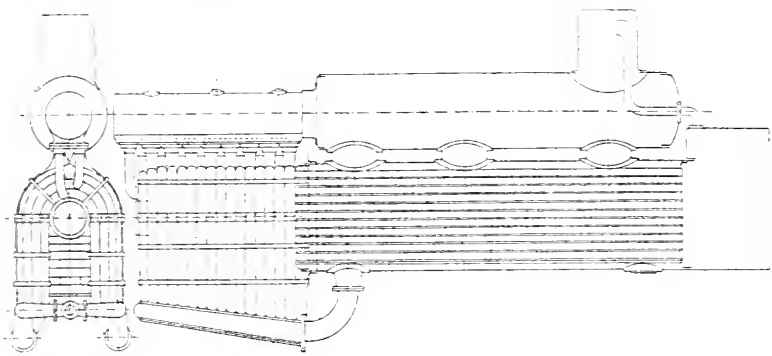
the tube-plate was so excessive that he had to abandon that means of construction. However he got over the difficulty in the third attempt in the following way. He cut the box out, as he had done before, but instead of having rigid tube-plates, he made the tube-plate curved as shown in Fig. 42, and then found that he had sufficient elasticity by that means to get all he wanted, without the trouble of the tube leakage he had before.* From the test made it

* "Engineering," 7 February 1879, page 114.

was found that slightly better evaporation was obtained, although not very much. What became of the system he did not know, but it was the most radical way of dealing with the fire-box trouble. The engine was using lignite, but whether anything of the kind would succeed in this country, where reasonably good coal was used, was quite a different matter. He thought Mr. Verderber had carried out his experiments in a very practical way beginning as shown in Fig. 40, and then getting over the difficulty in the manner shown in Fig. 42.

Fig. 43 * showed a further attempt which had been made quite recently, which was carried out by Mr. Brotan on the Austrian railways. That gentleman had done away with the whole box.

Fig. 43.—*Austrian Railway Water-Tube Locomotive Boiler* (Brotan).



At the bottom of the fire-box he placed what might be called a foundation-ring, except that it was hollow, and from that ring he brought the tubes up completely enclosing the furnace with tiles outside. The tubes were led into a cylinder or drum at the top which was connected with the end of the boiler in the barrel; and from the trials which had been made some very good results seemed to have been obtained. The boiler was fitted with a

* Reproduced from the Journal of the Austrian Engineers' and Architects' Society, 28 August 1903; see also "Engineering," 1 September 1905, page 276.

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connecting pipe between the bottom of the boiler barrel and the bottom of the fire-box.

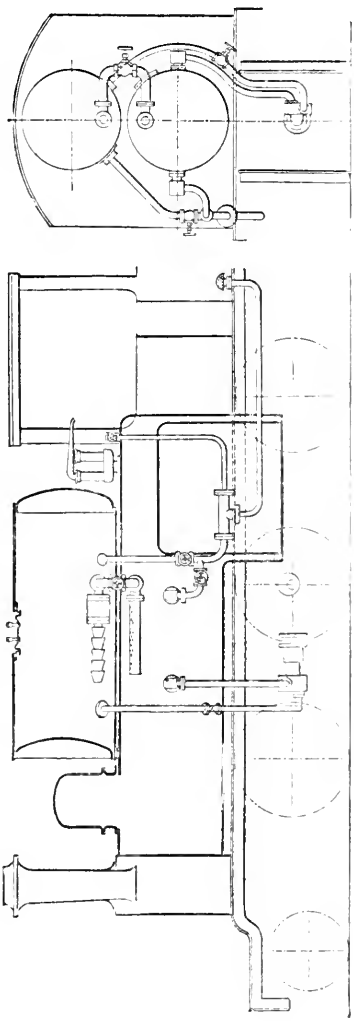


Fig. 44.—*Thermal Storage System* (Halpin) 1891.

One difficulty in introducing such circulating pipes was that they might interfere with the general arrangements of the engine and the axles, but if that objection could be obviated he thought it did give the necessary circulation.

Turning now to the subject of thermal storage, to which he would not have referred had Mr. Hughes not mentioned it, Fig. 44 showed the first arrangement in 1891. Steam was taken into the bottom of the vessel. There was an ordinary injector, which fed either into the boiler or into the thermal-storage vessel. There were cocks controlling the way the feed-water was to go, and when the vessel was as full as it was considered desirable it should be, the feed was taken out of it by a pump and sent back into the boiler. With reference to that design he must do himself the justice to say that he never had the hardihood to ask any locomotive engineer to adopt it and spoil the look of his engine by doing so. People said, and

probably justly, that he had spoiled the good looks of more engines in England than any other engineer, and he certainly agreed that such a mass of pipes and cocks and apparatus outside the engine was anything but an addition to its beauty. He therefore never attempted to get it introduced.

In 1896 a Russian engineer—Mr. Ruzenzoff—devised an arrangement which worked in a different way, Fig. 45 (page 202). There was a small cylinder on top of the boiler, which was filled up to 6 or 8 inches above the normal working level. When that had been done, an air-cock at the top of the storage vessel was opened to let the air it contained escape, and then a communication cock between the storage vessel and the boiler was opened and the extra charge of water was blown into the tank. One cock was then shut and another opened, and pressure being put on the top of the water, the boiler was fed with partially heated water. The attainment of the full temperature was a matter of the very greatest importance, and through the kindness of Messrs. Willans and Robinson he was able to find out the temperatures which were being obtained in the more recent types of such apparatus. In a nine hours' test of a Niclausse boiler the temperatures of both steam and water were taken over the whole day, the result being that the steam temperature was 372° F. and the water temperature 367° F., a drop of 5° F. or 1·35 per cent. In the case of the locomotive, Fig. 45, nothing like those temperatures could be obtained. In 1898 there were over two thousand engines at work in Russia. The Minister of Railways had had very elaborate tests made which were published in detail in the Journal of the Russian Government; and from those tests it was found that when burning coal they saved over 23 per cent. of fuel, and when burning oil they saved over 26 per cent., taking the same loads. If, on the other hand, they used as nearly as possible the same amount of coal as that which they had been previously burning, the engines took over 25 per cent. more load, and when burning good coal they took over 32 per cent. more load. He himself did not disagree with the figures which Mr. Hughes gave at the previous Meeting; but on

(Mr. Druitt Halpin.)

the engines which he would describe, a saving of only 4 per cent. was obtained.

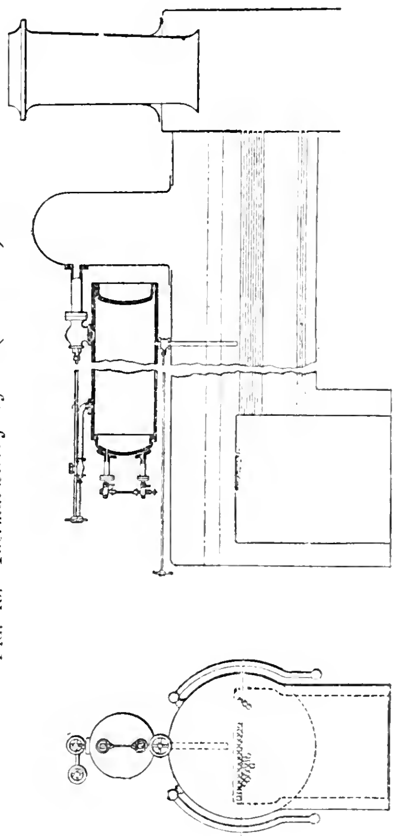


Fig. 45.—*Thermal Storage System* (Ruzenzoff) 1896.

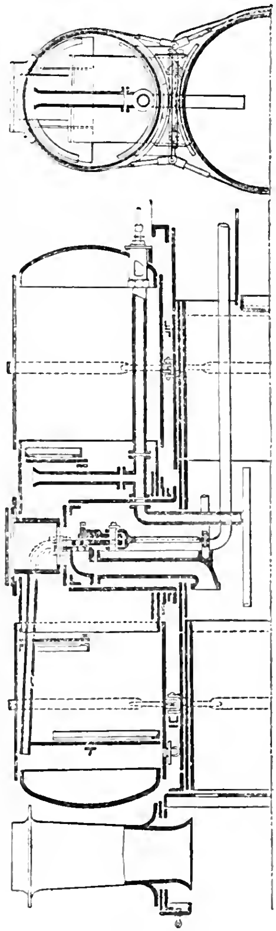


Fig. 46.—*Thermal Storage System* (Halpin) *on a 4-Coupled Tank-Engine L. and Y.*, 1901.

Fig. 46 (page 202) was a diagram of the engine Mr. Hughes referred to, one of the four-coupled tank-engines. It was not quite the same as the first one made. In the first one, the dome seating was left on the engine and the thermal-storage vessel was bolted to it.

An angle-iron was riveted at the base of the dome, and there was a manhole at the top for getting at the regulator. The dome-cover was taken off, and a hollow open-topped cylinder put in, simply to bring the whole of the steam right to the top. Some years ago, with the first apparatus, which was much less efficient than the present arrangement, on a stationary boiler, Professor Unwin made a two days' test, one day running a boiler with thermal storage and one day running without storage. The result there was 19·7 per cent. in favour of the storage system. On a subsequent test made by himself the results came to over 20 per cent. saving. His clients were so incredulous of the result that they made tests for themselves. They swept the bunkers out and cleaned the boilers. Starting under these conditions, and with a Schönheyder meter, which was calibrated before and after the test, they ran for twenty-eight days, day and night, including Sundays, and effected a saving of over 21 per cent.

Referring more directly to the Paper itself, he observed that nine-tenths of the trouble with large boilers arose from confined dimensions, the restrictions imposed in the first place by the gauge, and by the loading gauge, those due to the latter being exceptionally severe in this country. If it were possible to have the same proportions of loading gauge to gauge between the rails that was allowed in other countries, the results would be infinitely better.

Drawings had been recently published in the technical press showing engines used in South Africa on the 3-foot 6-inch gauge, having 19-inch by 26-inch cylinders. Such cylinders naturally required boilers which could not possibly have been adopted, if the engineers had been restricted to the gauge and the proportions of the loading gauge of this country.

The author had referred to the broad fire-boxes. In all fire-boxes, what was practically wanted was more grate area, and the question was how it was to be obtained—whether in length or in width. The author stated that in the wide boxes difficulty had been experienced with the men in getting them evenly fired, and also that a great deal of air leakage was obtained. He had always believed in having the box broad, and never could or would believe that the men

(Mr. Druitt Halpin.)

could fire enormously long boxes properly with grates running to 9-foot length, or could cover the fire properly. The tube troubles to which the author had referred were questions of temperature and pressure, but he thought there was also another question which had to be taken into consideration. Many years ago Mr. Stroudley had constructed a boiler in which the tubes had a slight camber, and as they were not put in straight, they could not act as struts, so that nothing could give. In that way he believed a good deal of the leakage troubles were got over. He did not know whether that arrangement was still being used.

The author had given some very interesting observations on the circulation in his boilers, and if he would give some further information, he thought it would be of great value. Mr. Churchward also said that the circulation, as far as could be judged, was so very delicate that by very slightly altering the mode of firing—which he took to mean firing one side or the other—they reversed the whole result. The question of circulation in boilers was most essential, and locomotive boilers, though they might not have the true circulation which the late Mr. Olrick used always to talk about in contradistinction to commotion, still had a most favourable action, which he thought was the cause of their generally giving such exceedingly favourable results. He believed it was in the year 1867 or 1868 that the Royal Agricultural Society made a very complete and most interesting series of tests on boilers at the Show, which he thought was held that year in Shrewsbury. An engine was run on the brake, and the whole of the details of water, coal, and the work done were taken. When those results had been obtained, the engine was run on the road across to Stafford from Shrewsbury, the results being noted with equal care, and it was found that when the engine was run on the road it evaporated a very much greater quantity of water per lb. of coal, and also evaporated a very much greater total quantity of water out of the boilers. He could only put that down to one cause then, and he had never since had reason to change his views, namely, that that action took place solely through the jumping, shaking, and jarring which the engine received. So impressed was he with that idea that, in conjunction with the late

Mr. Rapier of Ipswich, he had attempted to shake boilers artificially. A boiler with an area of about 800 to 900 square feet was obtained from the Great Eastern Railway Company, and by means of springs and cams they did everything they could, having an engine driving the shaking arrangement to reproduce the motion, artificially varying both the velocity and the amplitude of the oscillating movement, but in spite of everything they did they could not reproduce the chatter artificially, and after a year's hard work they had to give it up as no good.

The author also spoke of the great advantage of the cross-tubes in the boxes that were being used by Mr. Drummond on the London and South Western Railway. Very likely that was so because they were in a very efficient place, and they certainly gave very good circulation. In 1871 he was going through the Bristol and Exeter shops at Bristol, with Mr. Pearson, the then locomotive superintendent, and in anticipation of the change of gauge, some new narrow-gauge engines were being built; they were putting in the top of the box six copper conical tubes with flanges of about 4 inches diameter at one end and 5 inches at the other. The remarkable thing was that Mr. Pearson had cut these tubes out of old engines which had been fifteen or twenty years at work, and the tubes were still so good that he considered himself justified in putting them into brand new engines.

Mr. F. G. Wright thought there was no doubt that the subject of large locomotive boilers was an exceedingly important one for locomotive engineers, and while listening to the last speaker, and knowing that there was a certain amount of difficulty in finding room for the chimney, he had been wondering how he would expect to get an apparatus on the top of the boiler like the one he had been explaining. It seemed to him that the point must be viewed in a practical way. The locomotive engineer had been doing his very best to design and construct the most efficient boiler for high pressures and great power in the most economical way. From the experience he had gained in locomotive boilers, he thought there were two points which were often lost sight of, the first being the

(Mr. F. G. Wright.)
water used in the boiler, and the second the class of coal used for steaming the boiler. If more attention were paid to those two points, he thought the difficulties which existed with boilers in the present day would not be experienced. There was no doubt that the boiler was the greatest trouble every locomotive engineer had to contend with. It was the most expensive part of the locomotive, because invariably every time the engine came into the shops the boiler had to be taken off the frames for heavy repairs, which, of course, meant practically pulling the upper part of the engine to pieces. The experience which had been obtained on the Great Western since the introduction of water-softening plant pointed very pertinently to the necessity of softening waters which were not suitable for locomotive boilers. He knew from his own experience there were many places where the water was quite unsuitable for steam purposes, and that was the principal reason why so much tube trouble was experienced, and broken stays, and the heads of the stays eating off before the boilers had been at work many months.

Another point, which he did not quite see how they were to overcome, was that in very large boilers the engineers had been obliged to decrease the depth of the fire-box. With the older class of boiler, having deeper fire-boxes, the trouble was not experienced with the stays, which has taken place since the depth has been decreased, necessitating the boiler being fired with a comparatively thin fire, and the area of the depth of the fire-box in contact with the fire being very much reduced. The lengthening of the fire-box did not counteract this, as the depth was not increased where the heat was being applied to generate steam; that is, a boiler with a fire-box, say, 3 feet deep, had a certain area in contact with the fire, but if this were reduced, say, to 18 inches deep, the area had been reduced by half.

Mr. VAUGHAN PENDRED said that, before dealing with the main body of the Paper, he desired to say a few words with regard to the wide grates and the corrugated fire-boxes to which Mr. Halpin had alluded. The corrugated fire-box for locomotives was first used by the late Mr. Haswell. Personally, he had seen engines fitted with

the corrugated fire-box as far back as 1873. The fire-box was not cylindrical, although he believed Mr. Haswell patented it in that form, but was a vertical fire-box of the ordinary type with corrugations; and almost identically the same fire-box was afterwards used with very great success by Messrs. Garrett and Sons, of Leiston, for portable engines. In Belgium the wide fire-box had been carried to the farthest extent. He had seen fire-boxes with 70 square feet of grate, and recently in Belgium he saw a fire-box 9 feet wide and 7 feet long. Those fire-boxes were fired with coal, at the sight of which any English Engineer would show the greatest contempt—a kind of dead slack, which was fired on bars with about $\frac{1}{8}$-inch air space. There were two fire-doors, and the engineers did not appear to experience any particular difficulty in making very good steam, and also keeping good time with very heavy trains.

The Paper was just what a Paper ought to be—precise, to the point, and opening a large field for discussion. Indeed, the difficulty of dealing with it lay not in finding something to say, but in deciding what not to say, because time was short. He desired, in the first place, to remark that the introduction of the large boiler had given him great pleasure, because it was the strongest possible testimony to the soundness of the policy which he had advocated for twenty-five years, namely, that if plenty of heating and grate surface in the boiler were provided, the engine would take care of itself. It was an old story, that various attempts had been made to combine large cylinders with small boilers, notably on the Midland Railway. The result had been failure, because the drivers ran their engines "out of breath." The idea was, of course, that the engines should always be run well linked up, so as to secure an early cut-off and good measure of expansion; but this result could only be obtained in practice by augmenting the lap of the valves to an inch and a quarter or an inch and three-eighths, and with that great lap the engines were very apt to "go blind." He remembered proposing that the difficulty might be got over by drilling a small hole into the port at each end of the valve-seat, so that, although the port was closed, the hole being open would admit steam to the cylinder and the engine would start. Of course the hole was too small to affect

(Mr. Vaughan Pendred.)
the expansion. He had heard that the same thing had been done in the United States by filing a notch in the valve at each end.

The big boiler was with them, however, and it had come to stay. The diagrams in the Paper gave no idea of what the big boiler engine was like, and he had ventured to bring to the Meeting an engraving of one of the very latest examples of locomotive construction, namely, an engine of the Glasgow and South Western Railway.* It would be seen that the engine was big, but to stand on a platform beside the engine gave no adequate conception of its hugeness. It was necessary to stand beside the engine on the permanent way to realise its vastness. A few of the leading dimensions were as follows:—The cylinders were 20 inches diameter by 26 inches stroke; the heating surface was 1,852 square feet, made up of 131 square feet in the fire-box and 1,721 in the tubes, while the working pressure was 180 lbs. on the square inch. The weight of the engine and tender in working order was 117 tons 8 cwt., and of that 18 tons 1 cwt. was on the driving-wheels.

He would like to draw a comparison between that engine and Stroudley's "Grosvenor" on the London and Brighton Railway thirty years ago. He could remember when Stroudley's engines used to run to Brighton on one fire. The system of firing used was extremely clever and ingenious. The fire-box held about 15 cwt. or 16 cwt. of coal. The fire was lighted up a good while before the engine started, and the whole of the fire-box became filled with a dull red fuel. The engine was run with the front ash-pit dampers closed, and very little air was admitted under the grate except through the back ash-pit damper; nearly all the air came in through the fire-door. The result was that practically there was a gas producer at work, and a gas flame in the fire-box. With a train of perhaps 120 tons behind it, the engine used to arrive at Brighton with the coals in the fire-box all burned down to the bars. If the engine had had to go any distance beyond Brighton, that could not have been done, because it would be necessary to keep the fire up.

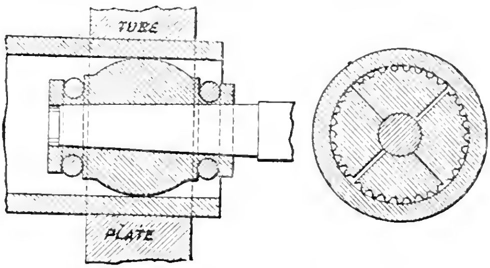
* "The Engineer," 29th December 1905, page 638.

The consideration of the large boiler could be approached from two points of view: firstly, that of the driver, and secondly, that of the works manager, Mr. King's point of view, for example. Any one who had stood on the foot-plate, as he had done, and seen a locomotive with a heavy train "like the side of a street," to use a driver's phrase, driven up a long incline at the top of its power and learned something of the high art of firing and driving, would understand the delight of having just the "little bit in hand" which the big boiler gave. On that matter he dared not dwell, because time was too short.

Turning to the difficulties which stood in the way and vexed the soul of the works manager, firstly, there were leaky tubes. Before a remedy could be found, the reason why tubes leaked must be ascertained. He would let the water question stand on one side, and only deal with the matter of construction. The favourite theory was that tubes slipped in the holes under the influence of expansion and contraction. It was worthy of notice, however, that all the leakage took place at the fire-box end, scarcely ever in the smoke-box. In support of the view that that slipping was the cause of leakage, the fact might be stated that if the tube-plate was free to pant there would be very little leakage. Mr. Churchward referred (page 167) to the leaving of a space between the tubes and the barrel, from top to bottom, to secure circulation. Benefit would result not because of better circulation, but because more space would be allowed between the sides of the internal fire-box and the tube ends, so that panting could take place, but he thought it could be proved that leakage occurred not so much because of sliding as because the metal of both the tube and the tube-plate had been punished by the expander. The metal had been stressed beyond its elastic limit, and therefore lost its grip. He would like to state, as an example of what he meant, an interesting fact which he learned some time ago at Messrs. Yarrow's Works. Every one present, no doubt, was acquainted with the construction of the Yarrow water-tube boiler. The tubes were rolled into the lower tube plate by a roller expander, worked with a motor and Stowe shaft. The plate was of steel an inch and sometimes an inch and a

(Mr. Vaughan Pendred.)
quarter thick. There was quite an inch left between the tubes, so there was a good body of metal to deal with; nevertheless, great skill was required. The rolling was by no means straightforward work; a mistake would cause the whole plate to warp and twist; a tube had to be put in here, and another there, and so on, to equalise stress, so that twisting would not take place. In the locomotive tube-plate of copper, the stressing was so localised to each tube that warping seldom took place, but the very softness of the copper was fatal to tightness. On one French railway, where they were much troubled with leaky tubes, they had, he understood, got over the difficulty by using a tube-plate 1¼ inch thick, and planishing that down under the planishing hammer to a thickness of 1 inch. The plate was thus hardened and stood up well to the tube. The ordinary

Fig. 47.—*Tube-Expander* (Exall).



Dudgeon expander was by no means an unmixed good; in its way it resembled the old "key" used by dentists for drawing teeth. The key had a hinged claw at one end, and a handle like that of a corkscrew at the other end, and it possessed the great merit that either the tooth came out, or the jawbone was broken, or the key was broken. The key, he might add, was very strong, so that the tube expander injudiciously used might work great harm.

Fig. 47 showed a diagram of a tube expander invented by the late Mr. Exall, of the firm of Barrett, Exall and Andrews, of Reading, many years ago. It was extremely simple, consisting of three, four or six segments, either in steel or chilled cast-iron. The use of the tool would be readily understood. It was put into the end of the tube, and the conical plug tapped with

light blows. The plug was withdrawn, the segments moved round, and the plug drawn in again. The whole secret lay in the milled edges of the segments, which acted in a most curious way in expanding the tube. He had had experience with hundreds of tubes set with that tool; none of them leaked, and tubes 4 inches in diameter were readily set with it. Much more might be said about tubes, but time would not allow it.

Passing on to the question of screwed stays, he had seen many kinds used, but engineers had always come back to the plain straight stay. In France, stays as much as $1\frac{1}{4}$ inch diameter had been used, and he was told with the best results. He thought it would be found, however, that the secret of success lay in making them long enough. The water spaces should never be less than 4 inches wide, for the sake of the box as well as the stays. His friend, Mr. Aspinall, had held that $2\frac{1}{2}$ inches was enough; but he still held his own opinion, and could never see any sense in curtailing water spaces. The gain in grate surface was nothing. Taking for example a grate 7 feet long, cutting an inch off each side, and adding to it the water space, the loss of area was 168 square inches, or a fraction over 1 square foot, say 5 per cent. He was as strong an advocate for a big grate as any man, but the boiler with the wide space would steam so much better, to say nothing of lasting longer, that he could not see how there could be two opinions as to which was the better design.

With regard to compounding, he was in full accord with Mr. Hughes, namely, that if it was to do good it ought to be with slow speed, not fast. Taking the case of an engine with 18-inch cylinders 26-inch stroke, allowing for clearance space, 4 cubic feet of steam would be required to fill the cylinder. Presuming the pressure to be 150 lbs. and the cut-off at one-third, then the terminal pressure would be about 50 lbs. Of course the figures were only approximate. Something less than 4 cubic feet of steam at 50 lbs. pressure were exhausted into the air; a reducing valve might just as well have been fitted on top of the boiler, and 4 cubic feet of steam at 50 lbs. pressure be allowed to escape into the air per stroke or 16 cubic feet per revolution. If the

(Mr. Vaughan Pendred.)

steam were expanded down to a terminal pressure of 25 lbs., then the waste was reduced by one-half. All that might seem a very crude way of stating things, but it was a way that would, he thought, be more understood than an elaborate statement of hypothetical logarithmic formulæ. The advantage secured by the compound system was all measured in terms of the reduction of the pressure at the time the exhaust-port opened. At slow speed, the compound system would reduce exhaust pressure in a way impossible with simple engines; but at high speeds, minimum exhaust pressure was obtained whether they wanted it or not.

In conclusion, he wished to say a word about feed-water. He thought the best possible place to put it into a boiler was the steam space at the smoke-box end, through a perforated pipe, which could readily be withdrawn for cleaning. There was a purely erroneous notion that steam would be condensed in quantity whenever the injector was turned on; as a matter of fact nothing of the kind occurred. The method had been used in stationary boilers with conspicuous success. The plates were spared strains, and deposit found its way readily to the mud drum. If that system were not used, then the feed-pipe should be directed inside the boiler, so as to deliver the water as near the surface as possible, preferably through a fan-shaped mouth, which would spread the water in a thin horizontal sheet. A cylindrical pipe with a row of perforations at each side would also do very well.

Mr. C. J. B. COOKE said he had been taken rather at a disadvantage in being called on to speak, because he had attended the meeting entirely as a learner and listener to the discussion on the most interesting Paper that had been read. He had been asked if he could give some idea of what had been done on the London and North Western Railway to overcome tube and stay troubles. He was afraid he was not prepared with any statistics bearing on the subject, but he could say that, under the new regime on the London and North Western Railway since Mr. Whale's appointment as Locomotive Superintendent, compounding had been done away with. Abolishing compounding had enabled boiler

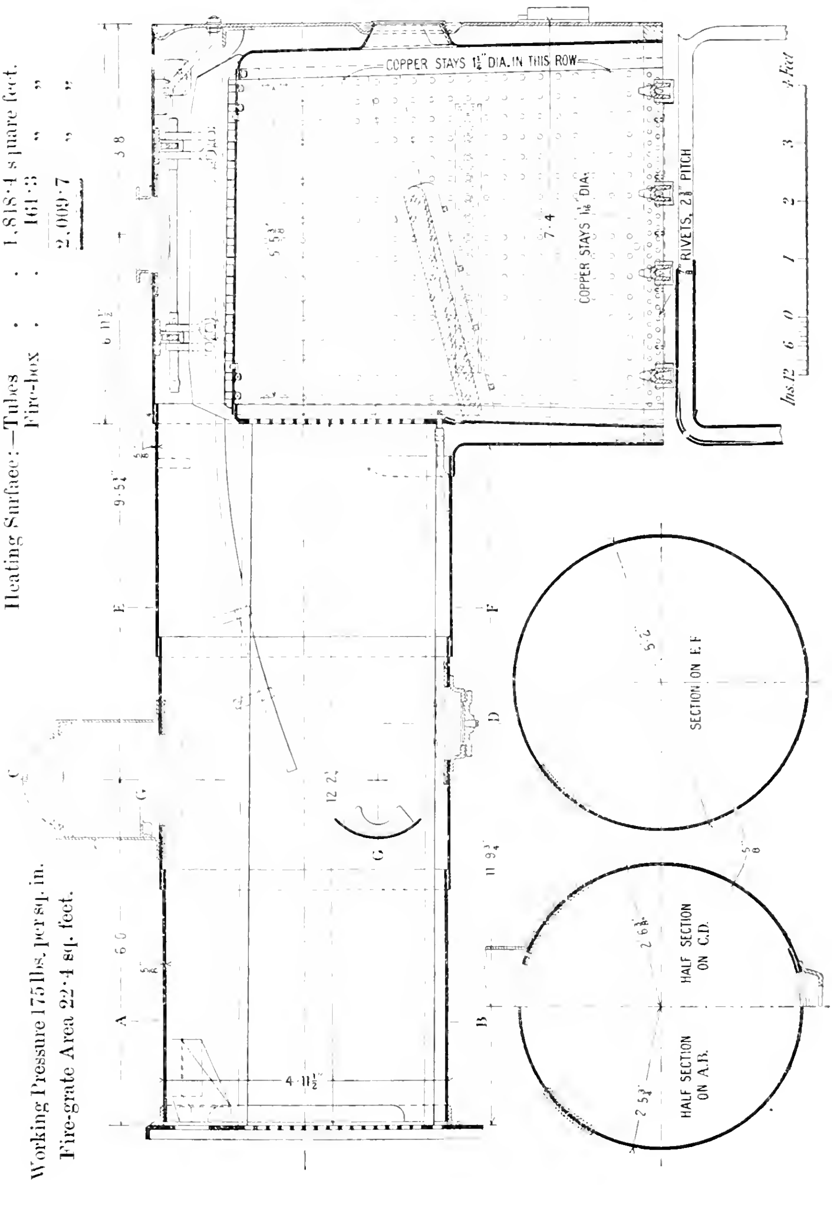
pressures to be reduced from 200 to 175 lbs. per square inch. Simple engines had been adopted, having large boilers, constructed on well-known, plain, straightforward lines, with a rather old-fashioned but most efficient type of deep fire-box; a type the advantages of which Mr. Wright, a former speaker, had alluded to. He had no doubt whatever that the reduction in pressure had a very great effect in reducing tube and stay troubles, and in minimising the work which had to be done at steam sheds and in the matter of boiler repairs when the engines came into the shops. He endorsed what Mr. Wright had said with regard to the importance of the coal and water question. People in the south of England had far greater troubles in connection with water than were known in the northern parts of the country, and it was a step in the right direction to do all that could be done in the way of softening water.

Another very important feature in connection with the question of tubes and stays was to keep a strict watch on the people who had to do with the engines after they were turned out of the shops and put into traffic. Many of the London and North Western boilers had to withstand the strain of running, every day in the week, from Liverpool to London and back, or Manchester to London and back (a weekly mileage per engine of 2,322 and 2,262 respectively), and unless the closest supervision was exercised, a systematic and critical inspection of boilers kept up, and everything done to avoid an accumulation of fast dirt, trouble was bound to ensue. The necessity for strict supervision in these matters he considered one of the most important factors in dealing with locomotive boilers. He wished to say, in conclusion, that the boiler which had been given in Mr. Churchward's Paper as representing London and North Western practice was one of the older type of boiler, Fig. 21, Plate 29. They were not now making boilers at Crewe with a "water-space and ash-pan"; he did not think it was a very practical idea, and in present practice ordinary foundation-rings were fitted, such as was shown in Fig. 48 (page 214), which represented the most recent large boiler for express engines built in Crewe Works.

(Mr. C. J. B. Cooke.)

Fig. 48.—*L. and N.W. Boiler for Standard Locomotive working the heaviest Express Passenger Trains on the Southern Division.*

(Contributed by permission of Mr. Geo. Whale, Chief Mechanical Engineer.)



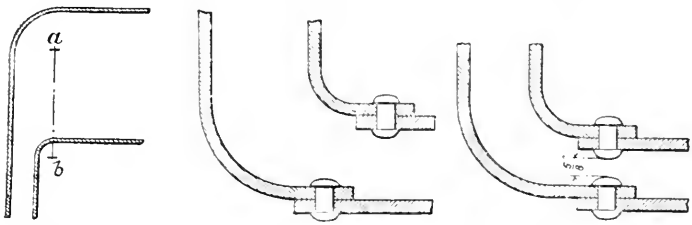
Mr. William H. Maw, Past-President, said he had not intended to speak on Mr. Churchward's interesting Paper that evening, as the time available for the author's reply was getting short, but there were some small points to which he would like to direct attention. It was proved by the Paper that engineers might depart very largely from ordinary patterns in the general construction of a locomotive boiler, and still get very satisfactory results. He thought the large number of diagrams which the author had added to his Paper showed that it was almost impossible to go wrong on the general outline of the shell of the boiler. But Mr. King at the last meeting very justly said that success greatly depended on thoroughly conscientious workmanship when dealing with large boilers and high pressures (page 194), and he (Mr. Maw) thought that, in addition to conscientious workmanship, very conscientious attention to small details was also required. It was upon the details of the construction of the boilers that engineers must largely depend for the success of the varying types of boilers that were before them. He was very glad to hear the author say he liked the Belpaire box. He (the speaker) happened to have designed a great many Belpaire boxes of different sizes, and was very pleased with the results he obtained; but he found there were two or three small points in relation to the Belpaire box that required to be attended to, if perfectly satisfactory working results were to be secured. One point which he had found was sometimes neglected was the relation which was desirable between the radii of the top corners of the inner fire-box and shell. Referring to Fig. 49 (page 216), if b was the centre of the curve of the inside box, then a, the centre of the curve of the corner of the outside shell, should be on the same vertical line. If this were not so, the widths of the flat portions of the crowns of the inside box and shell would be different. If the radius of the outside corner was too small, the flat top of the shell would be wider than that of the fire-box, and under pressure the top of the shell would tend to arch upwards pulling the fire-box crown with it. On the other hand, if the outside corner was made with too large a radius the flat portion of the inside fire-box would be in excess, and the two crowns would tend to arch downwards. In either case

(Mr. William H. Maw.)

variations of pressure would give rise to "breathing" of the shell, and that gave trouble with the staying. Another point was, that in the Belpaire boxes the area of the back plate was considerably larger than it was in an ordinary locomotive boiler, and more attention had to be paid to the longitudinal staying. He would be glad if the author in his reply would state how he stayed the back plate of the fire-box shells in the case of the conical barrel boilers he was now using. There was, he thought, a difficulty in those boilers of carrying stays right through.

Arrangements in corners of Fire-boxes.

FIG. 49. *Belpaire.* FIG. 50. *Over Foundation Ring.* *Good.* FIG. 51. *Bad.*



Mr. Halpin had spoken of the effect of vibration in improving the circulation in a locomotive boiler (page 205). Notwithstanding Mr. Halpin's non-successful experiment in artificial vibration, he thought there was a very great deal in what that gentleman had said. Every locomotive man who used locomotive boilers for stationary purposes had it brought home to him rather strongly that a boiler would not do such good work when it was stationary as it would when on a locomotive. Any small defects in the way of a bad circulation were accentuated very much when a boiler was fixed. He would almost say that if an engineer desired in a short space of time to find out what the weaknesses of a new type of locomotive boiler were, he would obtain the experience more promptly by using it as a fixed boiler than on a locomotive.

There was one other point in connection with the circulation to which he desired to direct attention, namely, the advantage of using rather a wide water-space under the barrel. It was a very common

thing for this water-space to be run rather close. In the Great Western boilers illustrated in the Paper, it would be found that this water-space was wide. In using locomotive boilers for stationary work, he had found it an advantage to increase the front water-space up to $6\frac{1}{2}$ inches. It had the very good effect that when the boiler was working hard an ample supply of water was obtained to the fire-box sides, without interfering with the supply that had to flow upwards through the tubes close to the tube-plate.

There was another advantage in the wide front water-space which was a sort of by-product. Supposing the sketch, Fig. 50 (page 216), was a plan of the front corner of a locomotive fire-box; if there was a wide front water-space it was possible to get the two vertical lines of rivets of the fire-box and shell well clear from each other. When there was a narrow front water-space, it very often happened that these two rows of rivet-heads came so close together as to greatly obstruct the waterway. He remembered that some fifteen years ago he was asked to examine into the design of a rather large locomotive boiler which had been used on shipboard and with which great trouble had been experienced. In that case the front end of the fire-box had been widened out with a view to getting as many tubes in as possible, and the water-space was reduced in consequence. He found, when he drew a section through the front corner of the fire-box, that the two lines of rivets just mentioned came directly opposite each other, so that there was only $\frac{5}{8}$ inch space left between the rivet-heads as shown by the sketch, Fig. 51 (page 216). The consequence was that the whole of the lower rows of stays of the fire-box leaked and the fire-box plates were very quickly injured. He thought it might be of interest to draw attention to those two or three points of detail.

Mr. Lawford H. Fry said that the Paper called attention to the large size of American locomotive boilers. It might be interesting to notice some instances of the work done by the locomotives described which would show how far the great size of the American boilers was due to the arduous requirements of the service. For example, the Chicago, Burlington and Quincy

(Mr. Lawford H. Fry.)

boiler shown in Fig. 9, Plate 23, belonged to an engine which hauled a passenger train of ten cars weighing 430 English tons, exclusive of engine and tender, at 48 miles on hour, on a division with an average rise of 1 in 218 and a maximum rise 15 miles long of 1 in 155. That engine had shown itself capable of taking a twelve-car train weighing 495 tons over that division at 42 miles an hour. Four stops were made, but these were not included in the speed mentioned. The Atchison, Topeka, and Santa Fé tandem compound, of which the boiler was shown in Fig. 4, Plate 20, hauled trains of 1,200 tons behind the tender at an average speed of 20 miles an hour on an up-and-down run with ruling grades of about 1 in 150. In a recent Paper before the New York Railroad Club, Mr. Mullfeld, of the Baltimore and Ohio Railroad, described the performance of the Mallet type engine of Fig. 1, Plate 19. On a division with an average rise of 1 in 236 and a ruling grade of 1 in 100, that engine hauled 2,120 tons of cars and lading (thirty-six cars) at an average speed of 10½ miles an hour.

In America, as elsewhere, fire-box and flue troubles had increased as the size of the locomotive had increased. Those troubles seemed, however, not to be directly due to the increase in size of the boilers, but to the increase in pressure and in duty which had taken place at the same time as the increase in size. In endeavouring to overcome boiler troubles, two points were of the first importance, namely, the quality of the water and the circulation of the water in the boiler. The American railroads were now devoting a great deal of care to the securing of pure water. Water-purifying appliances were being installed in large numbers, and care was given to the proper choice of a water supply. For example, on the main line of the Pennsylvania Railroad a special pumping station had been built, and an arrangement had been made with a neighbouring water company to supply water of good quality to the points at which the locomotives took water. He would quote only two instances of water-softening plants. On the Union Pacific Railroad water-softeners capable of purifying 3,000,000 gallons a day had been installed in the bad water districts; and the Pittsburg and Lake Erie Railroad had equipped the entire road with water-softeners.

A Committee of the Master Mechanics' Association reported at the meeting last year that the cost of purifying water for locomotive use was more than offset by the reduction in the labour cost of caring for the boilers in the round-house, and the benefit gained by the freedom from leaky flues was clear profit. On a division of the Union Pacific Railroad where the water was particularly bad the introduction of the use of soft water had increased the length of life of the flues from about six or ten months to two and a half years. Given good water, it was necessary to feed it to the boiler properly.

Mr. Wells, of the Chicago, Burlington and Quincy Railroad, had shown that the use of the injector while the locomotive was standing was a very fruitful source of tube trouble. The cold water being fed into the boiler while there was no active steam production in process would sink to the bottom of the barrel and of the water-spaces. There was thus produced a considerable difference of temperature, which might amount to 200° between the upper part of the boiler and the lower. That produced an uneven expansion which caused the tubes to leak. Mr. Wells had succeeded in showing clearly that a very large proportion of leaky flue-sheets was due to this cause, and that the trouble could be cured by feeding only when the engine was in working and by delivering the water so that it should mix immediately with the heated water in the boiler. The stay-bolts and fire-box side-sheets suffered from a lack of circulation in the water-spaces. The most vigorous evaporation took place from the fire-box side-sheets, and, as Mr. Churchward had pointed out, an unimpeded circulation was necessary so that the water evaporated might be readily replaced. The water-space should be as wide as practicable, and should be designed to promote the natural circulation of the water and the steam. The steam should be enabled to rise from the fire-box sheets without interfering with the water descending to replace it. In a wide fire-box over the wheels, that condition was obtained by making the fire-box side-sheets vertical, or by making the crown-sheet wider than the grate, so that the side-sheets sloped outwards in rising from the foundation-ring. Fig. 4, Plate 20, illustrated that condition.

(Mr. Lawford H. Fry.)
There the tendency of the steam to rise vertically carried it in an almost continuous film up the fire-box side-sheets, while the replacing water could descend without interruption along the sides of the fire-box casing. If the fire-box sheets sloped inwards in rising, that was if the crown-sheet was narrower than the grate, the steam in rising vertically would leave the fire-box side-sheets and penetrate and interfere with the descending current of water. If that condition was combined with narrow water-spaces and the boiler was forced, the steam lifted the water bodily away from the side-sheets; the sheets were overheated, and stay-bolt and side-sheet failures resulted. That was illustrated by an experience some years ago on the Chicago, Burlington and Quincy Railroad. A series of engines were built with inwardly sloping side-sheets, and almost from their start in service the stay-bolts gave trouble. There was a certain area towards the upper part of the centre of the side-sheets within which it was almost impossible to keep the stays tight. That area corresponded to the maximum steam production and minimum water supply. The trouble was removed by re-modelling the fire-box and making the side-sheets approximately vertical. In America steel fire-boxes with iron stay-bolts and wrought-iron or steel flues were of course the universal practice. The stay-bolts were usually 1 inch in diameter, spaced from $3\frac{3}{4}$ to 4 inches apart, and had tell-tale holes $\frac{3}{16}$ inch in diameter, drilled in $1\frac{1}{4}$ inches from the outside to show if the bolt broke in service.

American engineers had not accepted the large locomotives without questioning the desirability of their use, but in service the large engines had given satisfactory results. The Pennsylvania Railroad standard consolidation engine, Class H6a, of which over 500 had been recently delivered by the Baldwin Locomotive Works, had 2,843 square feet of heating surface. The Atchison, Topeka, and Santa Fé had in service 135 tandem compound engines with the boiler shown in Fig. 4, Plate 20, which had nearly 4,800 square feet of heating surface. The Baltimore and Ohio Mallet compound, with 5,600 square feet, had given such encouraging results that the Great Northern Railway of America was having five still larger Mallet engines built. Those engines would have 5,700 square feet of heating

surface, and 78 square feet of grate, and would weigh in working order exclusive of tender 158 tons 9 cwt. There would be two high-pressure cylinders, 23 inches diameter by 32 inches stroke, and two low-pressure cylinders, 35 inches diameter with a stroke of 32 inches.

Mr. W. H. Moss said that the point he discussed some years ago, and which it appeared had induced the Chairman to call him, was the relative merits of the simple and compound system as tried on the London and North Western Railway, but Mr. Churchward's Paper dealt exclusively with the boiler question. He was not a locomotive engineer, but a marine engineer; but it appeared to him that in a locomotive boiler the main question to be considered was the circulation of the water. In a marine boiler, the circulation was almost altogether in the vertical plane, but in a locomotive boiler the circulation appeared to be mainly longitudinal. The stream of water, as far as he understood, rose from the hottest part of the furnace in a marine boiler, that is, from the centre line of the crown of the furnace. Now in a locomotive boiler, working under a strong suction or induced draught, there would be a tendency to draw the flame or hot gases towards a point. That was seen, for example, when watching a fire at home; when there was flame it always appeared to draw towards a point, and in a locomotive boiler with a strong induced draught he would think there was a tendency to concentration of heat towards the vertical centre line of the front plate of the fire-box. In the large boilers used at the present day, the extreme width across the tubes was greater than the width of the grate; on the other hand, in the wide fire-box mentioned in the Paper the width of the grate was more than the width across the tubes. In that form of fire-box, the heat from leaving the fire surface had a tendency to draw up towards a point underneath the brick arch before it came over it, and when over the arch it impinged upon the tube-plate with greater intensity at the centre than at the sides, and might cause distortion. He thought it might assist the circulation if the central vertical row of tubes were omitted altogether. He did not know what the experience of

(Mr. W. H. Moss.)
locomotive engineers was, but marine engineers found that a few square feet of tube heating surface was neither here nor there; and he would think that if the centre vertical row of tubes, especially in the wide fire-boxes, was omitted, dividing the tubes into two blocks, it would be an advantage to the boiler. There would be a clear space fronting the centre of the fire-box where the most intense heat impinged on the tube-plate, which would allow the water to get away freely, and would allow the colder water to flow in to take its place. It might have an effect in drawing water from the sides of the boiler in towards the central space, but in any case he thought it would initiate a current towards the front end of the boiler, and would maintain a more rapid circulation. At sea many years ago, although it had not been done so much of late, it was a common enough thing, if a boiler primed, to take out a vertical row of tubes over the furnace crown, and that generally cured the trouble by improving the circulation.

Mr. Hughes had said that he thought something must be done, and the speaker thought locomotive engineers might find a certain amount of relief in studying the question of the mechanical efficiency of the engine. The boilers had of late increased very considerably in size, and it had been stated that that was necessary because the work to be done was harder, the trains were heavier, and had to be run faster, so more power was required. At the same time, the size of the cylinders, as a rule, had been considerably increased also. The boilers generated more steam, but concurrently there was a greater demand for steam to overcome the increased internal resistance of the engine itself, due to larger cylinders, and all connected up to the crank-axle. The point in locomotive practice which he could not understand was this. It was known that, given a certain weight of steam, the higher the pressure, the smaller its bulk; and in marine practice right up to the present day, the higher the working pressure the smaller had become the engine for any power required. On the other hand, in locomotive practice, as a rule, although the pressure of steam had increased, the cylinder capacity had increased also. Locomotive engineers aimed at high rates of expansion. Granted that was desirable, still it cost

nothing in coal to raise the steam to a higher pressure; so a very little extra expansion was a net gain. Supposing an engineer were using, say, 17-inch cylinders with 24 inches stroke, and 150 lbs. pressure of steam, and he desired to use steam at 200 lbs. pressure, the boiler capacity being unchanged, the rate of expansion of the steam must of necessity be increased. Then, if larger cylinders also were used, it might not be possible to secure a profitable rate of expansion. He thought the modern practice in locomotive engineering was to fix the maximum cut-off at a point as little past the half-stroke as would enable the engine to start in any position, this conducing to a better distribution of steam when running. As higher pressures were used, the greater was the weight of steam that must be admitted to the cylinders at starting, and where larger cylinders were used the drain on the boiler was still heavier, while the difficulty of securing a satisfactory distribution of steam when running was increased. It would appear as if a remedy would be found in being content with smaller cylinders than were usual, with higher pressure of steam, or in compounding.

Mr. Churchward, in reply, said he stated at the outset that, in compiling his Paper, one of its main purposes was to provoke discussion and argument at the meeting. He felt pleased that there had been so much useful discussion, and he was very grateful to the speakers, a great many of whom had put forward good ideas, and had, as he had claimed for his Paper, given food for thought. Mr. Hughes, of the Lancashire and Yorkshire Railway, started by touching the crucial spot in the whole of their dealings with the modern large locomotive boiler, namely, softened water (page 178). That was, in his opinion, the secret of using the modern high-pressure high-capacity boiler. He believed it was commercially impracticable to maintain the pressure and dimensions to which engineers had arrived, not only in America, but also in this country, unless the water question was dealt with. It must also be remembered that the pressures and dimensions were still steadily increasing. It was perfectly hopeless to try to cure boiler troubles when the scale-forming ingredients were present in

(Mr. Churchward.)

the boiler; they must be taken out before the water was fed into the boiler. His own company was softening water pretty generally, and their experience was that tube troubles with the higher pressures between 200 and 225 lbs. had been so moderated by the softening of the water, that, in effect, they did not get more trouble with softened water under the higher pressures than they previously had with hard water and lower pressures. In addition there was the efficiency obtained by using the higher pressures, because, in spite of what one of the speakers had said, more units of work per ton of coal used were obtained if the higher pressures were used properly than from the lower pressures.

Mr. Hughes also touched upon the question of the storage heat (page 183), and in addition the members had had the privilege of hearing a good explanation of that point from Mr. Halpin. If the diagrams of the boilers given in the Paper were studied closely, it would be found that that storage of heat was obtained in the boilers themselves to a very large extent. For instance, in the Great Western standard boilers, there was a clear 2-foot space between the roof of the fire-box and the top side of the casing. When there was a clear space, 2 feet in depth, an average of 5 feet wide, and say 9 feet long, in addition to what could be got into a 15-foot barrel, it was evident that, above the working limits of water, say 5 inches on the top of the box, there was room to put a very large amount of water into the boiler, and they could put water in going down hill and were able to use the steam produced going up. It really amounted to the statement that the larger boiler gave the ordinary engine-driver more ability and more facility to practise that engine-driving trick than he had with the older boiler, and that was one of the greatest factors which made the larger boilers in the end very much more efficient and economical than the older and smaller ones. He had seen that for himself, and other engineers who had been over in France had told him that they had also seen it practised to a great extent upon the modern high-pressure French boilers.

Then Mr. Hughes referred to the question of piston-valves. He was afraid it was impossible to go into that subject in the course of

his reply, but if Mr. Hughes would read a Paper on the subject, he would personally like an opportunity of joining in the discussion. Mr. Hughes also said he had found the advantage of compounding at slow rather than at high speeds. He believed that had been perhaps not the common experience, although a very general one, but it might be of interest if he said it had not been the experience of the Great Western with the French four-cylinder compound engine. That engine had been doing her best compound work most decidedly at high speeds. The French compound would pull two tons at seventy miles an hour on the draw-bar, and it took a remarkably good locomotive to do that.

He was exceedingly sorry their old friend Mr. James Stirling was not present that evening, because he felt really hurt that that gentleman should have said that he (Mr. Churchward) had so disgracefully spoiled the appearance of the British locomotive. He knew that he had been accused of spoiling the appearance of the British locomotive as much as any man in the country, but he took exception to the statement. In his opinion, there was no canon of art in regard to the appearance of a locomotive or a machine, except that which an engineer had set up for himself, by observing from time to time types of engines which he had been led from his nursery days upwards to admire. For instance, people liked to see a long boiler, with an immense driving-wheel about 8 feet in diameter, just like the old Great Western broad-gauge engines. Engineers must admit that the time had gone by for studying appearances in the construction of the locomotive boiler at any rate. One speaker rather criticised the observation he had made with regard to wide fire-boxes burning poorer coal, and said that that had not been successfully accomplished in some cases with which he had dealt. The only reply he could make to that criticism was, that either the coal must have been too poor or the box not wide enough; he could see no other reason. Then a speaker had referred to the leakage in the tubes of English engines as compared with American. He did not desire to say for a moment that leaky tubes were not found on English engines, because it was obvious to everybody that they were, but they certainly had not obtained that

(Mr. Churchward.)
extraordinary excess of tube leakage which it was supposed they would get from the way in which pressures and temperatures had been put up. He was afraid he could hardly deal with the criticism that the cone connection between the tapered boiler was specially arranged for butting into snow-drifts, although there was a good deal in the suggestion. If one had a very long boiler, 27 to 30 feet long, and it was carried fairly full of water, when the train was going up hill or down hill, or when the brake was put on, or when the driver accelerated quickly, there was a tremendous flush of water, so that if the front of the barrel was narrowed down into the smallest diameter in which the tubes could be spaced, not very much room was left for the water to swish off the box. That was quite an important point in the long boiler, although the members would understand that it did not especially apply to snow-drifts.

Mr. George E. Jones (page 196) alluded to the probable trouble experienced from the use of different materials in the tubes in the barrel and the boiler respectively. He believed there was a good deal in that question, which some locomotive engineers had not studied enough. It was perfectly clear to him that, with lengths of tubes of 15 or 20 feet in a barrel, the difference in expansion between one metal and another became quite worthy of consideration.

Mr. Halpin had alluded to the evolution of the principle by which the locomotive fire-box was to be done away with. That had interested him very much, because he had often been scheming to try and do away with the locomotive fire-box, but he always got to just the sort of collection of tubes running in all kinds of directions which Mr. Halpin had showed, so that in the end he never had the courage to construct anything of the sort; because when he looked at the number of joints, &c., he concluded there was just as much room for trouble in doing away with the box as there was in maintaining it. He was therefore going to do the best he could with the box as it stood.

Mr. Halpin also alluded to the difficulty of firing the long boxes (page 204). That he believed was a difficulty, or an assumed difficulty, against which a great many people had run their heads

quite unnecessarily. It had been found on the Great Western, that both in the French engines and in their own engines, with a proper slope of the boxes, a 9 or 10-foot box could be fired without any difficulty whatever. As a matter of fact, some of the 9 and 10-foot boxes that were running at present were more easily fired and easier to work on the foot-plate than a number of the old 6 and 8-foot boxes cut on the straight. If the members would keep in their mind's eye for a moment the short flat portion that went over the trailing axle in the ordinary long box and then the considerable bit of slope that ran down, it would be found that 75 per cent., he would say, of the coal was put on to the flat part of the box and the rest fed down. There was really no trouble whatever in that respect, and the difficulty of firing was no argument to his mind against the long boxes at all.

The shaking of the boiler was a very old pet subject for discussion. It was said that the locomotive boiler was not such a wonderful boiler, because it only steamed when it was shaken up at high speed. He had never agreed with that statement, and could not understand it. If they imagined for a moment a locomotive boiler put down to work stationary, and a pair of 18 by 30-inch cylinders under it working at 300 or 350 revolutions a minute, and cutting off at 20 per cent., there would be something going up the funnel of that boiler which would make it steam. When an engine was running through the air at high speed, there was a considerable air-pressure. There was not only induced draught due to the jet apparatus in the smoke-box, but there was also practically a closed stoke-hole, with a pressure feed of air from underneath, which made a considerable difference.

Mr. Wright was severe on the shallow box, and so he thought was Mr. Cooke, and he really was himself; but if one had to get a longer box than could be placed between the driving-wheels, there seemed to him no possible way but having a shallow box, and the engineer must do the best he could under the circumstances.

He was glad to hear Mr. Pendred defending a long lap on the valves (page 207). The Great Western used a very long lap, but they had got over the difficulty which he quoted by increasing the

(Mr. Churchward.)

travel of the valve, so that the engine would not stick on the centre. The usual valve openings could be obtained, namely, that they were able to cut off as long as 75 per cent., in which case no sticking would take place. The observations Mr. Pendred made with regard to feeding the water into the steam space also interested him exceedingly. His friend, Mr. King, and himself were working a good deal on that question at Swindon; they were trying to devise some practicable means by which the water could be fed through the steam, and not let it touch the water in the boiler at all until it had passed through a certain amount of steam. He had heard of such arrangements which had been very successful, and personally he could see no reasonable objection to the feeding of the water in that method. It would certainly prevent those local differences in temperature in the water of the boiler which were undoubtedly the cause of a great deal of boiler trouble. If it was of any interest to Mr. Pendred, he would tell him that he meant pursuing the plan of feeding the water through the steam as thoroughly as he could until he managed to get some success with it.

He was very interested to hear Mr. Cooke say that the pressures on the London and North Western were being reduced (page 213). He wished that he (Mr. Churchward) felt that he was in a position to reduce the pressures on the Great Western, and he therefore congratulated Mr. Cooke on having got to that happy frame of mind in regard to locomotive working. The plain and simple type of boiler to which Mr. Cooke alluded was undoubtedly desirable, and he quite realised that the London and North Western engineers were having very much less trouble with the plain, simple and straightforward boiler which they were building today than they had with such boilers as had been illustrated in the Paper.

In regard to the Belpaire box, Mr. Maw pointed out a very important feature in regard to the curves of the plates (page 215). That was the main difficulty experienced in designing a Belpaire box, which had to be quite balanced in all directions. The arrangement of the curves became very serious at the bottom corners, where the rivets were brought opposite each other.

In the Great Western Belpaire boiler, the width of the back plate was reduced, so that they were in the same position as when they started, namely, that they could get their direct stays clear through from plate to plate, and the area was well balanced. The back plate was being made 4 feet 9 inches wide.

Mr. Fry had alluded (page 219) to the working of the injectors when the engine was standing. He quite agreed that a great deal of trouble was caused in that manner. A careless fireman, for instance, had to stand for an hour with far too much fire ; he blew off, and put on the injector, and there was no doubt that very serious local differences were caused in the temperature of the boiler by so doing. Feeding the water through the steam no doubt would get over some of them. One of the main questions upon which he expected to have to reply was the fact that in the Great Western boiler, at any rate, no sling stays were used; straight stays were used from the front to the back of the box. He wondered very much why that point had not been alluded to. He had found that the sling stays were quite unnecessary. Twenty boilers of one pattern had been built, ten having three rows of slings over the tube-plate, and the other ten with direct stays from end to end ; the working of the twenty boilers was carefully watched, and it was found that there was really no difference; there was nothing to encourage one to put the slings in. He desired to thank the Members very heartily indeed for the kind attention they had given him, and for the very flattering and interesting discussion which the Paper had called forth.

Communications.

Mr. J. R. BAZIN wrote that it was an undoubted fact that the chief form of development in the modern locomotive during recent years had been the great increase in the size of the boiler, and it was now generally acknowledged that the efficiency of the machine, in dealing with heavy loads at high speeds, had been more increased by providing boilers of enormous capacity than in any other improvement in the general design. A striking example of this was shown among Mr. Ivatt's express locomotives on the Great Northern Railway. On this line there were two distinct types, each type comprising two classes; these latter only differed from one another in the size and capacity of the boilers placed upon them. The first type (4–4–0) had cylinders 17½ by 26 inches and driving-wheels 6 feet 8 inches, the heating surface of the boilers of the two classes being 1,123 square feet and 1,250 square feet respectively; the second type (4–4–2) had cylinders 18¾ inches by 24 inches with driving-wheels 6 feet 8 inches diameter, the heating surface of the boilers of the two classes being 1,440 square feet and 2,500 square feet, and the working pressure of these boilers being 170 and 175 lbs. per square inch respectively. The difference in the efficiency of the engines with the larger boilers was very marked in their working, and it was interesting to note that, although employed on much heavier work, their average coal consumption did not show any great increase when compared with the small-boilered engines used on lighter jobs.

By the employment of a large boiler with 2,500 square feet of heating surface, it had been found possible to increase the size of the blast-pipe top from 5 to 5½ inches with cylinders 18¾ inches by 24 inches, thus causing a less fierce draught on the fire and consequently a reduction in the coal consumption, while at the same time not affecting the steaming capacity on account of the amount of reserve steam in the large boiler.

It is to these boilers with 2,500 square feet of heating surface that the wide fire-box was fitted, and the success of this type of box

from the first had been so marked that no less than forty-two boilers with wide boxes had been constructed at Doncaster, and were giving great satisfaction on the main line. These boilers had given very little trouble with regard to tubes or stays leaking, the chief complaint being leaking mouthpiece rivets; the mouthpieces of these fire-boxes were formed with a narrow ring, the copper plate being "dished" round it. Thus the rivets should be protected somewhat from the action of the flame, but the boxes being so shallow the mouthpiece rivets were subjected to intense heat, and the flame seemed to lick round the dished portion as much as with the ordinary ring.

With regard to tube trouble, these boilers had been remarkably free from any leakage; in fact, there were several instances where the ferrules had not been touched save for an occasional "knock-up" for seventeen or eighteen months, and in each case the engines had been employed all the time on heavy express work. It was the general practice to send these engines out new without any ferrules, the tubes simply being expanded in the fire-box tube-plate; they ran thus for a few weeks, or until it was found necessary to put ferrules in them; this gave the tubes a chance to bed themselves to the copper tube-plate, and so when the ferrules were put in they were not so liable to shake loose and allow the ferrules to slack back. The tubes were of iron $2\frac{1}{4}$ inches diameter, and had copper ends brazed on the fire-box end.

On many of the long narrow fire-boxes used on the smaller 4–4–2 class and the eight-coupled coal engines, the copper plates below the brick arch had been "cupped" round the stays, so that when the heads were riveted over they were practically level with the fire-box sides. This undoubtedly was effectual in protecting the heads from the flame; but it was found that when any leaking took place, dirt formed round the stay-head in the "cup" and was liable to corrode the stay round the back of the head; unless the heads were very carefully examined and kept well riveted over, trouble was likely to arise from this cause.

Mr. C. E. Cardew wrote, in continuation of the remarks he made at the Meeting (page 186) on the Hornish mechanical boiler-

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cleaner as fitted to a locomotive boiler, Fig. 36 (page 192) that, from his experience with it, he had found that by using a suitable boiler-detergent to bring the scale away from plates and tubes as formed, the cleaner was capable of removing it all, even where exceedingly bad water was in use. For many hard brackish waters, particularly those liable to priming, he had found a concentrated decoction of eucalyptus leaves very efficacious. For waters heavily charged with calcic carbonate, as met with in streams rising in and running through mountain limestone, sodic arsenite was the most efficacious. In an Appendix (below) was given the method of preparing and using both these detergents, neither of which had he found to have the smallest detrimental chemical effect on the plates and tubes of the boiler treated with them. On many railways in India, and other countries where the traffic was light, it did not pay to instal special plant for the purification of the feed-water at the several watering stations. In such cases the employment of an effective but harmless detergent in the boilers was almost a necessity, as it greatly conduced to efficient working and the reduction of cost for the maintenance and repair of the boilers.

APPENDIX.

Methods of Preparation and Use of Eucalyptus Extract and of Sodic Arsenite as Detergents for Removing and Preventing Scale in Locomotive Boilers.

Eucalyptus.—A decoction is made of leaves of the eucalyptus blue gum-tree of Australia. The leaves (green or dried) are well bruised and then digested in a steam-heated boiling-pan, with just sufficient water to ensure the whole of the vegetable matter being extracted from them in one boiling, the duration of which must be decided by experience. The decoction so obtained is then concentrated in an evaporating-pan till it becomes a fully saturated solution of the extract. It is then bottled and stored for distribution as required.

As a detergent, one or two pints of the above saturated solution (according to size of boiler) put into it after the periodical wash-out will be sufficient; or it may be introduced in the feed-water from the tank, or by suction of the injector through its overflow-cock. If in some cases it causes priming it will suffice to introduce the above, or a stronger, dose through the overflow-cock, the last thing before drawing the fire prior to the periodical wash-out, and then allow the boiler to stand at least eight hours before running the water out of it. In any case eucalyptus commences to act as a detergent at once, so that even in heavily scaled boilers the fire-box inner sheets will be quite clean in less than a month, though it may take longer to free the other plates and the tubes of all scale.

A very highly concentrated viscous extract of eucalyptus is imported from Australia for certain manufacturing purposes. Suitably diluted it could no doubt be successfully used as a boiler detergent.

Sodic Arsenite.—The solution may be made thus:—Take 1 lb. of white arsenic (arsenious acid) and about 2 lbs. to $2\frac{1}{2}$ lbs. of soda-ash, or other crude sodic carbonate (the exact quantity must be decided by an analytical chemist, according to the purity or crudeness of the carbonate employed). Pound these ingredients separately. Dissolve the soda-ash in one imperial quart of soft water, heating it gently to assist solution. Allow the decoction to settle, and pour off the clear fluid into another vessel, throwing the residue away. Then add the pounded white arsenic to the clear fluid, heating the mixture slowly, but not boiling. Hydrogen gas is soon evolved: stir the mixture till it ceases. The resulting combination is a saturated solution of sodic arsenite. When cool it may be bottled like the extract of eucalyptus.

For use in boilers as a protection against scale, or in ones only lightly scaled, from one to two imperial quarts of the saturated solution a week will suffice. The quantity employed should be introduced in two equal portions, the first immediately after the periodical wash-out and the second about forty-eight hours before the fire is drawn prior to the next wash-out. For heavily scaled boilers the doses may be from one to two quarts a day (according to

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the size of boiler) for four days in succession, and after this a wash-out on the seventh day from commencing the treatment.

To get the full economical value of the solution it is necessary that all fluid put into the boiler should operate for at least forty-eight hours. Hence the necessity for deferring the stoppage of the engine for a wash-out until that time has elapsed after the last dose.

Hornish Mechanical Boiler Cleaner.—Where this device is in use it is equally important to use a suitable detergent as in boilers not fitted with it, if not indeed more so; for it is very desirable that any scale deposited shall come away as soon as formed, small both in quantity and size, so that the cleaner may deal with it easily. As however its regular use is constantly decreasing the strength of the solution of the detergent in the boiler, it will be necessary to employ this in larger quantities or for longer periods than described above, but these must be determined by experiment in each case. In extreme cases where boilers have been allowed by neglect to get very badly scaled it will probably be advisable to stop the use of the Hornish cleaner for a few days, until the bulk of the scale has come away by means of ordinary wash-outs, after which there would be no fear of its getting blocked with large lumps of hard scale.

Mr. P. J. COWAN wrote that the Paper dealt with a subject of great importance, not only to engineers, but to all interested in the economy on railways. The boiler was the starting point of motive power, and if it were uneconomical the most efficient valve-gear and mechanism would only reduce losses already made, instead of the whole unit being one of high efficiency.

The historical remarks concerning the relation of cylinders to boiler (page 174), which, by the way, it was rather strange to see at the end of the Paper, gave the key to the whole story of development of locomotive boilers during the last six years. In England in 1899 a good-sized boiler was considered one of 53 inches diameter with a heating surface of 1,100 square feet. A boiler of 56 inches internal diameter was then termed a "large" one, and no great effort was required to recall statements by head-draughtsmen

and others to the effect that that was the largest it was possible to introduce with the gauge limits in this country. But by careful study and experiment it had been found possible to obtain, with suitable arrangements, boilers of an internal diameter of 64 inches, with a heating surface of more than double that considered ample six or seven years ago.

With the growth in general size the grates had of necessity increased in dimensions, and the most striking departures from old practice were, perhaps, noticeable in this direction. It was a remarkable fact that seven out of the ten American boilers illustrated in the Paper had wide or moderately wide grates. Only three years ago the new type of grate, that is, the moderately wide grate, was looked upon in this country as simply "another American fad." The writer thought that this, and what remained of that impression today, was and had been due largely to the utter failure on the part of many engineers in this country to understand thoroughly the motives which, in the first instance, prompted American engineers to branch out in this direction. On page 166 was a statement which indirectly was at the bottom of the whole matter. It was there stated that the "wide box evidently requires a higher standard of skill on the part of the fireman." It was when attention was drawn to the lack of skill on the part of the fireman, to which in turn notice was attracted by the huge consumption of long-grate boilers on their modern engines, that American designers sought relief in the direction of the wider and shorter grate. It should here be stated that there was a distinct difference between the "wide" and the "moderately wide" box, though lack of distinctive titles had led to confusion in the minds of some not fully acquainted with American practice. The "moderately wide" box was used to replace the long and narrow box for bituminous coal burning; the "wide" had altered little for many years, and was used with a type of fuel altogether different. Both types were, however, confused under the all-embracing term of "wide."

American engineers found that with the enormous length to which grates had to be extended in order to obtain anything like sufficient grate area (in some cases lengths of 10 and even 11 feet),

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firemen ran with heavy fires, and firing generally was of a most wasteful description. Even the best fireman could not easily fire level grates, as these were, of this length. Attention then turned naturally to greater economy, and it was found that the wider grates entailed greater care on the part of the fireman, and could, without a doubt, be fired more economically. On this subject a report of the Association of Master Mechanics of America was very interesting. In dealing with the modern boiler question, in answer to an inquiry as to whether saving was found to result from the use of the wide grate, replies were received from roads all but two of which reported economy. Saving reported by eleven roads varied from 5 to 40 per cent., freight engines showing rather more than passenger engines; and the committee concluded that a very appreciable saving resulted from the use of this type in distinction to the long and narrow box. Further, the report stated that in reply to questions as to what proportion of the new engines built or purchased were being fitted with wide fire-box boilers, such answers as the following were received, namely:—Three roads report that no wide fire-box engines are in use; ten roads report that all new engines are fitted with wide fire-boxes; two roads, all but switching engines; one road, 75 per cent. of the engines; one road, 200 wide fire-box engines in four years; one road, all new and changing old, replacing boilers with narrow grates by those having wide fire-boxes. It was the general opinion that the moderately wide grate caused less trouble with stays and side-sheets; seven roads reporting less, three roads much less, one 50 per cent. less, two roads very much less, and only three roads no difference. These were the opinions of men who had been chosen for their positions quite as much for their ability and efficient management as were the locomotive superintendents in other countries, and their opinions should therefore carry a certain amount of weight.

In connection with the grate question and remarks made by Mr. Cardew (page 187) on the unsatisfactory results obtained with a wide fire-box engine under his care, the writer would suggest, with all deference to Mr. Cardew and with all respect to the builders of the engine referred to, that to go to builders as authorities on these

matters might not always be the means of procuring either what was best or most suitable. In such an entirely new departure, as this evidently was on the Burma Railways, he would submit that a railroad official, rather than a contractor, should be approached on the matter. It appeared to the writer that one of the leading superintendents of motive power, on a road using both types of engines, would be in a much better position to balance nicely the required features of a locomotive than gentlemen, however clever, who had but little to do with the engines after they left the shops. He did not wish by any means to minimise the knowledge or ability of builders, but he held that they were handicapped in the matter of the accumulation of data which every motive-power official could command. Tests of new engines on roads, witnessed by builders' representatives, however nearly they might approximate to road and service conditions, were as nothing compared with the knowledge a motive-power official might collect after prolonged use of a particular type of engine. Considering their position, he considered builders as a rule acquitted themselves uncommonly well when consulted by purchasers, but he submitted that possibly more satisfactory results would have attended such trials as Mr. Cardew made, had he been enabled to obtain the design of his locomotive from a road official having a wide knowledge of fuels, the engine being subsequently built by any selected contractor. In this way he thought that engines of greater suitability might sometimes be obtained, and the trial of a new type would be made under conditions when the results would be of greater value.

The experiment referred to (page 168) was, he imagined, one made on the Chicago and North Western Railway. He remembered seeing, in 1899, in the Great Northern shops at Doncaster, an 8-foot single rebuild being fitted with a bifurcated circulation pipe of this description. The pipe was carried from the bottom of the barrel to the lowest and widest positions on the throat-sheet. It was fairly straight, with no curves which would take up expansion or allow for the alteration in length of the barrel due to difference in temperatures. Unfortunately, he was not in a position to give the results of the experiments, as he had

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since heard nothing of the trial, but he thought it might well be recorded that while the Chicago and North Western trials were conducted in 1902, Mr. Ivatt of the Great Northern had been working on the same ground years before. Perhaps the author could furnish further particulars concerning this.

With regard to the statement (page 169) relating to the flat top of the fire-box and casing, he thought it was a matter of considerable surprise that the flat-topped casing was not adopted universally (provided that the height of boiler centre and the loading gauge admitted of its use), when the results obtained in their use were admittedly, almost without exception, of a satisfactory nature.

With regard to the dome, its position and use, the author remarked that he had in some cases abolished it. The Great Eastern Railway used to have the dome as far forward as possible, though latterly the position had been somewhat modified. As the water over the fire-box was supposed to be in a state of great agitation and commotion from the upward rush of steam from the sides and roof of the box, he would be glad if the author would give his views on the matter of dryness of steam obtained from over the box, or at the far end of the barrel, and whether the advantage of drawing the steam from the quieter regions at the front end of the boiler would be lessened by the fact that at that point the steam would be slightly lower in temperature, and therefore wetter from this cause.

Mention was made in the discussion of the Vanderbilt box. He believed he was correct in stating that, when first bringing out his design, Mr. C. Vanderbilt acknowledged in the Press that he had been working on the development of previous Continental designs rather than on altogether original lines. From recent information received, the Vanderbilt box was not considered altogether satisfactory, and the type was not received with favour by the men at least, on the American continent.

The only omissions he regretted in the Paper were those of reference to work being done in Germany and other countries on the Continent. Engines well worthy of attention by British engineers were in use on many Continental lines. For instance, Messrs. Maffei of Munich had built recently wide fire-box engines of no mean

dimensions, of a heating surface of 2,396 square feet, and a grate area of 40·8 square feet.

With regard to the advantages of good water, it might be of interest to mention that on the Egyptian State Railways there were broken up, in 1904, some engines by Stephenson which had been in service for forty-eight years without needing new boilers; and there were still running, at least as recently as the early part of 1905, old 14-inch by 22-inch cylinders, 6-foot single-driver Crampton type engines built in 1855. Though taken off train work, they were then performing satisfactorily duties for which other engines could not well be taken without considerable extra expense. These latter engines had had the barrels only partially renewed.

Mr. James Holden wrote that, as regards the question of leaky tubes in wide fire-boxes, there were, he thought, factors other than the mere width of box to be considered. In America brick arches were not used to any great extent, and when they were used a fairly large space was left between the arch and tube-sheet, the consequences being that cold air impinged on the tubes and leaks resulted. To lessen this trouble, drivers would, where possible, run with their front dampers shut and back dampers open.

There was another point worth some consideration. Wide boxes were almost universally stayed with direct stays, and although Belpaire boxes were similarly treated, the boxes with which wide boxes were frequently compared were those stayed with girders or roof bars. Now the pressure on the top of a box 6 feet 6 inches long by 4 feet wide was about 330 tons, and in a direct-stayed box this pressure was directly balanced through the stays by an equal pressure on the outside wrapper plate. In a box fitted with longitudinal girder stays nearly the whole of this pressure was transmitted through the tube-sheet and the back sheet of the fire-box proper to the foundation-ring. There was thus a considerable pressure always tending to prevent a distortion of the tube-sheet in an upward direction, and not only this, when tubes were expanded the tube-sheet must either remain practically firm or the girders must be bent. The short stays in the water space prevented to a

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great extent distortion sideways. In a direct-stayed box the stays at the tube-sheet end were almost always made flexible; they allowed, therefore, an upward expansion of the tube-sheet independently of the main portion of the box, the tightness of the tubes depending upon the power to resist distortion possessed by the tube-sheet alone. At first sight it might appear that the sling-stays, used in conjunction with roof bars, stayed the crown of fire-box directly with the outside wrapper; but of course they could only be looked upon as safety appliances, for, no matter how tightly they were fitted, directly the fire-box became hot, it expanded more than the outside of the boiler and the slings became loose.

As regards water-tubes in the fire-box, these appeared at first sight to be a somewhat complicated means of converting a bad steaming engine into a good one, but this was a matter quite open to controversy, and some comparative figures would be interesting. So soon as an engine obtained a name as a remarkably good steamer it would almost always be found to have a shallow fire-box. The writer had known bad steamers turned into good ones by cutting a foot or so off the bottom of the fire-box. In a shallow box the flames licked the top of the box as they passed over the arch, and gave out considerable heat through the crown; but if the box was deep they did not lick the crown-sheet, but passed into the longitudinal tubes without giving out much heat through the top of the fire-box. In this latter case tubes passing through the fire-box at a correct height would of course extract considerable heat, but, personally, he would expect a shallow box to be superior after taking all things into consideration.

As regards the life of locomotive boilers, although it was considerably shortened in the case of large boilers, it was not due to their size that this shortening of life occurred, but rather to the high pressures they carried. In fact, small boilers carrying high pressures wore out quicker than larger boilers carrying the same pressure and doing the same work. The average life of a boiler, not unduly forced, pressed to 140 lbs. might be taken at twelve years, and one pressed to 180 lbs. at ten years.

The following Table comparing different engines might be of interest. The results were obtained in connection with some acceleration trials the writer carried out in the year 1903. Forty-three electric contacts were used on a level stretch of road; data in table was obtained at 1st, 30th, and 43rd contact, the 30th contact being 0·125 mile and the 43rd 0·256 mile from 1st contact. In all cases engines started from rest and pulled a load in addition to themselves of about 250 tons, and were worked with regulator full open and in full forward gear. It would be seen that the boilers of the last two engines were capable of maintaining a comparatively small tractive force when they had once got under way, whereas the second engine on the list, which was fitted with the same boiler as that used for the fourth engine, could not maintain a tractive force of 23,480. This boiler is shown on Fig. 20, Plate 28.

TABLE 2.

Type of Engine.	Grate Area.	Heating Surface.	Tractive Force.	Water used.	Time in seconds from rest to 30th contact.	Time in seconds from rest to 43rd contact.	Boiler Pressure.		
							Start.	Contact 30.	Contact 43.
	sq. ft.	sq. ft.		galls.					
0–10–0 wide box	42	3,010	37,419	193	30	46	203	178	175
0–6–0	21	1,630	23,480	88	36·3	54·3	195	175	165
0–6–0	14	976	18,417	62·5	38·9	57·9	185	165	153
4–4–0	21	1,630	16,725	98	43·5	65·4	185	175	175
2–4–0	21	1,476	12,145	89	49·6	72·5	175	170	170

One other point might be of interest. Stays and stay-tubes were sometimes used in large boilers. These produced quite unnecessary strains. Table 3 (page 242) gives the force required to pull either a $1\frac{1}{4}$-inch copper fire-box tube-plate or a $\frac{3}{4}$-inch steel smoke-box tube-plate over a single steel tube when cold. The tube tested was $1\frac{3}{4}$ inch outside diameter, No. 13 S.W.G., with the smoke-box end $1\frac{7}{8}$ inch

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TABLE 3.

No.	How fitted.	1st Test on each. Plate in which Joint started.	1st Test: Loads in Tons. To start Joint.	1st Test: Loads in Tons. Max.	1st Test: Plate through which Tube pulled.	2nd Test on each. Loads in Tons. To start Joint.	2nd Test: Loads in Tons. Max.	2nd Test: Plate through which Tube pulled.
1	. . . .	Steel	4·64	5·95	Steel	5·95	6·4	Copper
2	Tube expanded in parallel holes (no beading).	Steel and copper	5·1	5·77	Steel	5·1	6·6	Copper
3	. . . .	Copper	3·5	3·9	Copper	5·45	6·75	Steel
4	. . . .	Steel and copper	5·9	5·99	Steel	5·9	9·3	Copper
5	Tube expanded in taper holes (no beading).	Steel	5·86	7·5	Steel	6·9	8·5	Copper
6	. . . .	Copper	5·8	6·45	Steel	5·8	7·9	Copper*
7	. . . .	Steel	6·7	6·7	Steel	9·0	12·35	Copper
8	Tube expanded in parallel holes and beaded over on copper plate.	Steel	3·7	3·7	Steel	9·2	13·4	Copper
9	. . . .	Steel	4·5	8·16	Steel	10·3	11·95	Copper
10	. . . .	Steel	5·44	6·75	Steel	8·1	13·0	Copper
11	Tube expanded in taper holes and beaded over on copper plate.	Steel	6·1	7·9	Steel	9·4	13·4	Copper
12	. . . .	Steel	4·55	4·85	Steel	9·1	11·5	Copper

NOTE.—In the 2nd Test the end previously pulled through plate was flattened and held in dies.

* Steel started at 6·1 tons.

diameter and fire-box end $1\frac{5}{8}$ inch diameter, no ferrules being used. Parallel holes and slightly taper holes were tried. A further test, after considerable heating of the test-pieces, gave results slightly lower than those shown.

Mr. F. A. Lart thought that English engineers, with that wise conservatism and cautious endeavour which still distinguished them from foreign engineers, had unanimously come to the conclusion that the standard type of locomotive boiler was the most satisfactory in general design, and also that its undoubted efficiency was directly due, and in proportion, to its simplicity. He would urge upon those responsible for British locomotive practice that they should not be ready, on some slight pretext of "progress," to sacrifice the looks of an engine. On the other hand, the gradual abolition of steam domes was a return to former practice. He was glad to note the disappearance of safety-valves from the domes. If more escape room was required, the usual 3-inch valves could easily be made 4 inches. For himself, whenever he had found his engine blowing off, he immediately put on the injector, no matter how full the boiler might be; it was more economical to do that than, literally, to blow the coal out of the safety-valve; and a very little water, with a slight adjustment of the fire-hole door and of the safety-valve lever, would bring the valves back to their seats. With regard to injectors, he was sorry to see that the already over-complicated locomotive of recent date had in some cases been supplied with auxiliary injector-pumps. He thought that when the London, Brighton and South Coast Railway had given up the eccentric injector-pump and the cross-head pump there remained no engineer who doubted the efficiency and absolute reliability of the modern injector, no matter what the class of water used. He thought the injector feed-water, no matter what its temperature might be, should be fed well forward into the barrel, the last two feet of the pipes being well perforated with $\frac{1}{4}$-inch holes. He viewed with misgiving the unnecessary and growing complexity of the modern locomotive, and the directly proportionate decrease of its ton-efficiency, which he thought was the best basis of comparison between locomotives.

(Mr. F. A. Lart.)

The essentials of an efficient locomotive boiler would probably be generally allowed to be these:—(1) Simplicity of general and detail design; (2) Copper fire-box, tubes, and stays; (3) Large water-spaces round the fire-box; (4) Ample steam and water-space above the fire-box and tubes; (5) Tubes not less or more than 2 inches external diameter, with a minimum bridge of 1 inch; thick front tube-plate, and back tube-plate thick enough to give the tubes a good bearing; (6) Direct roof stays, flexible at the front end: this demanded a flat-topped fire-box, and preferably outer box also; (7) Barrel of boiler not larger than would properly accommodate a sufficient number of tubes; and (8) Tubes rather too long than too short. With regard to the latter point, while the length of tubes was primarily decided by the size of the engine, and secondly by convenience, he thought it was a mistake to suppose that very long tubes, especially 2-inch tubes, were useless with regard to the heating value of their extremities. The gases from the fire-box passed so quickly through the tubes during the working of the engine that not only was their combustion incomplete but their heat was not greatly diminished by the time they reached the smoke-box. This was admitted by some engineers, who very sensibly made the smoke-box serve as a superheater for the steam or the feed-water. This was probably an economical idea, though it involved some complication, and increased weight in the wrong quarter. He did not see how tubes could be too long, especially if some simple arrangement of induced water circulation from the front end to the back of the boiler could be fitted, either inside or outside, such as the Cawley arrangement which he had seen experimented with in Glasgow and applied with obvious success to some locomotive boilers. In this point largely lay, he thought, the future development of locomotive-boiler economy and efficiency. The author touched upon this, but seemed to fear difficulties in outside piping.

With regard to the thickness of tube-plates, he did not see that a thick front plate, which was not meant to radiate heat, and gave a good bearing for the tubes, could be any disadvantage; in the back tube-plate the tubes should also have the maximum possible bearing, and as the heating surface between them was relatively small, a

thick plate, say 1 inch, would be rather advantageous than otherwise, and of course it would be fined down to ½ inch below. Tubes should be ferruled at the fire-box ends. While he advocated copper tubes as being on all grounds the most economical and efficient, he admitted that they wore more rapidly than other tubes; but with 2-inch tubes and a softer blast from a larger blast-pipe orifice than was customary, this wear and tear of tubes would be greatly reduced. He thought that the larger boiler was decidedly the more efficient, and that a very large grate area in proportion to the heating surface was not as absolutely necessary as some engineers seemed to think. What they did want was perfect combustion of the fuel on the grate and in the box, and no erosive, wasteful particles of incandescent fuel escaping through the tubes. That was why he advocated a more gentle draught; and he believed that with a relatively small grate and large heating surface more duty was got out of the unit of fuel; there was less wastage of heat as the ample heating surfaces absorbed to the utmost all the heat that came to them, and there was less wear and tear all round. No matter what the steam-pressure required might be, such a boiler did not require any heavier firing, but actually less, than those huge boxes which seemed to be the mistaken pride of some engineers nowadays. He had had experience of the design and satisfactory working of Mr. M'Intosh's large Dunalastair engines. These boilers, while they had a large barrel and tube heating-surface, had only a relatively small fire-box and grate area, of the normal type: added to that, they burnt Scotch coal, which was poor slack stuff, and the most extravagant of all British coal; but he had never seen any firing so light and simple as on these engines, nor been on an engine that took such heavy trains over such heavy roads so easily.

He thought that the heavy forced draught due to the small blast-pipe orifice was a mistake. It caused tremendous wear and tear throughout the whole boiler, wasted the fuel, and shortened the life and reduced the efficiency of the boiler to a lamentable degree. With regard to boiler pressure, he thought that 200 lbs. per square inch was quite high enough, and that 180 lbs. was preferable. He did not think that to get these high pressures any boiler required to

(Mr. F. A. Lart.)

be unduly forced; it was chiefly a matter of loading the safety-valves; and to keep up a sufficient constant supply of steam for large cylinders more was got by working a boiler quietly and thoroughly than by forcing a cooling stream of air through it and half burning the fuel. Amongst the many special devices for increasing the boiler efficiency the Drummond water-tube arrangement was probably the most desirable, theoretically; but he thought the arrangement involved so many mechanical difficulties that it was not expedient. He did not care for the new design of horseshoe fire-box spread over the frames. The type possessed many obvious structural disadvantages itself and involved others in the general design of the engine: also it gave what he considered an excessive grate area, disproportionate especially to the fire-box heating surface, and which, if the engineer determined to have it, could quite as well be obtained on the ordinary English lines, as had been amply demonstrated. The sloping inner fire-box back-plate was a good idea, as old as the locomotive itself, designed by Stephenson in his Rocket. He thought, however, that it should slope more to the current of the draught inside, as in the Canadian Pacific Railway boiler, Fig. 19, Plate 28, than as shown on the "De Glehn" boiler shown in the author's illustrations, Fig. 15, Plate 26. He saw no advantage in the American idea of reducing the front end of the barrel: it was expensive. He believed the Great Western Railway were the first to recognise the advantage of large outer fire-boxes and steam space; indeed, the old broad-gauge engines were the pioneers of it, and it was found also in the old McConnell engines of the London and North Western Railway. It was a satisfaction to him, in fact, to see in some quarters so many signs of a return to the sound simple principles of early locomotive practice. To get the utmost out of any locomotive it should be worked, not beyond, but fully up to its capacity, and be kept in hard and constant work all its days, between necessary repairs representing high mileage.

Mr. R. M. LIVESEY wrote that the author said (page 167), "The water to feed up the spaces between the tubes near the back tube-

plate has to be drawn almost entirely from the front of barrel, and it is possible that in some cases the space left for this purpose is inadequate." In the writer's experience this was very often the case in narrow as well as in wide fire-boxes, and he had often found a great improvement by dispensing with a few of the lower tubes. The writer also was of opinion that the water-spaces at the side of the fire-boxes might be increased with advantage, by considerably increasing the taper of the water-space. By so doing, according to his experience, the tube and stay troubles have been very considerably lessened.

He was somewhat disappointed that no mention had been made of boilers with circular fire-boxes either of the plain or corrugated type, and comparatively recently, while abroad, he had the pleasure of experimenting with boilers so constructed, and with very successful results. The writer would be glad to know whether the boiler of this type built by the Lancashire and Yorkshire Railway Company had come up to expectations, as he had seen no mention of it recently. He had, amongst others, under his charge a number of locomotives of one type, the boilers of which, though well designed and constructed, were never free from tube or stay troubles. This was mainly due to the extremely bad water which had to be used, and which could not be improved at reasonable cost. Every possible measure was tried in order to mitigate the trouble; copper fire-boxes with brass tubes were sometimes completely worn out in four to six months. Low Moor iron fire-boxes, with stays of same material, and steel tubes and shells were tried with slightly better results; then all-steel boilers were tried with still better results (their life was about two years), but still not satisfactory. The writer then designed an experimental boiler with a circular fire-box, using the existing barrel, and so arranged matters that very few alterations to the engine were required. The first one was very successful. Stay troubles, of course, disappeared and tube troubles were greatly reduced, and after a little experience it was found that the latter could be entirely eliminated by withdrawing the tube every two months and thoroughly cleaning the interior of the boiler. It was done piecework at a very low cost. This being so satisfactory,

(Mr. R. M. Livesey.)

thirteen locomotives of the one type were fitted with the new boiler as quickly as possible and all with equally satisfactory results.

Before the advent of this type it was difficult to keep 25 per cent. of the locomotives on the road; after their introduction, however, the writer was able to keep practically 100 per cent. of them running for a very busy period of about two years. They have now been at work for upwards of six years, and without having to renew any part they are still as good as new. He was confident that still better results could have been obtained had the whole engine been designed at one time and to suit the new type of boiler, but he had to make the boiler suit an existing engine, which somewhat cramped his efforts. Apart from the absence of trouble with this type of boiler, it was of course very much cheaper and easier to build than any other. Steel was used throughout, and all of the mildest quality; it was also very much more easily and cheaply taken to pieces. On several occasions when pressed for locomotive power, and to save time, the writer has had one of these locomotives come into the shop after finishing work on Saturday afternoon; the cab was removed, fire-box and tubes withdrawn and cleaned, and all replaced and the engine at work again on Monday morning. This could not be done with the ordinary type of boiler. In view of the success obtained with these boilers, he found it difficult to understand why they had not been more widely used, and would be glad of further information on this point. The runs were all short, but the loads and gradients were always severe and the engines were invariably worked up to their utmost capacity. Further, he found that the "circular" type of boiler steamed much more easily and was much more economical in coal than the other. The reasons appeared fairly obvious.

Mr. R. E. L. MAUNSELL wrote that the statement made in the beginning of the Paper, that the modern locomotive question was principally a question of boiler, was one with which he thought most locomotive engineers would cordially agree. Until comparatively a few years ago, anyone possessing average experience in boiler repairs could forecast with a certain degree of accuracy what

repairs would be necessary to the boiler of a locomotive after running a certain mileage, provided he knew the condition of the boiler when it last left the shops after repairs, and the class of work on which the engine had since been engaged. Tube, stay, and other fire-box troubles, although they existed to a certain extent, were then not the causes of worry and alarm that they had been in recent years. Nowadays when engines engaged on express passenger or goods work came into shops for repairs, it was impossible to say what the extent of the fire-box repairs would be until a careful examination had been made; and the result of such examination was seldom comforting to the person responsible for maintenance.

To meet the modern conditions of traffic—both goods and passenger—locomotive engineers had been compelled to adopt large boilers with greatly increased heating surface and higher pressures, and so exacting were these conditions, that the desire to obtain the maximum heating surface in the boiler of the modern locomotive had probably resulted in too little consideration being given to the question of adequate provision for circulation. The author's suggestion that neglect of this consideration was the cause of three-fourths of the tube troubles in these large boilers would, he thought, commend itself not only to those engineers who had suffered from these troubles in the large modern boilers but more especially to others who, through inability to provide quickly enough locomotives sufficiently powerful to meet modern traffic requirements, were compelled to meet these requirements by "forcing" the boilers of engines, obviously too small for the duty they were called on to perform. Immediately "forcing" was resorted to, tube and fire-box troubles of every kind, which were previously unknown to any extent, became alarmingly prevalent, due, he believed, to exactly the same cause to which Mr. Churchward attributed the tube troubles in the large boilers, namely, insufficient means of circulation.

In the case of the modern large boilers with high pressure, as Mr. Churchward pointed out, the temperature of evaporation was so much increased that additional provision for circulation was necessary. In the case of the "forced" boiler there was no increase of pressure,

(Mr. R. E. L. Maunsell.)

and, therefore, the temperature of evaporation remained exactly as it was before, but the rate of evaporation was largely increased, due to a largely increased consumption of fuel per square foot of grate area per hour; consequently the provision of circulation, which was adequate when the boiler was doing the work for which it was originally designed, was hopelessly inadequate when the boiler was "forced" and the rate of evaporation increased. As pointed out by Mr. King (page 195), improvements could, no doubt, be made in some cases where leaky tubes existed, by careful attention to the manner in which expanding was done, but the writer was convinced that no system of expanding yet devised would remedy leaky tubes in boilers constructed with insufficient provision for circulation. The constant references in the American technical press to leaky tube troubles on the railways in that country led the writer at one time to assume, erroneously he now believed, that these troubles were caused to a large extent by steel plates being used for fire-box construction in the place of the copper plates universally used in this country; and when he visited the United States in 1904 he gave this subject a good deal of attention, as he felt particularly sympathetic towards anyone suffering from troubles of this kind. In every railroad shop he visited, he made it a point of asking to be allowed to examine the fire-boxes of engines standing in the shops for repairs, and in every case permission to do so was courteously granted. He carefully examined a large number of fire-boxes of engines undergoing repairs, and also old fire-boxes lying out on scrap heaps. He subsequently obtained as much information as possible of the mileage run by the engines, the fire-boxes of which he had examined, the class of work upon which they had been engaged, and the quality of the water in the districts in which they had been at work.

Briefly, the result of his investigation was that he was greatly impressed with the condition of the fire-boxes he had examined. He only found two cases of plates cracked about stay-holes, but in neither case did the crack extend from stay-hole to stay-hole, and these were probably caused by the plate becoming overheated, due to an accumulation of scale. The condition of the tube-plates

was good, particularly in respect of freedom from cracks between the tube-holes, and distortion of tube-holes, caused by frequent expanding, so common in copper tube-plates. This was, no doubt, due to the greater resistance offered by the steel plate as compared with the soft copper plate. Several of the fire-boxes he examined had, he was informed, run over 200,000 miles without any of the plates being renewed or patched, and inquiries as to the quality of the water led him to believe that on the whole it was inferior to the quality of the water available for locomotive purposes in this country. It was difficult to make any comparison between the returns of engine failure due to leaking tubes on the American railways and railways at home, due to the more rigorous definition of a failure in the former country. On the railroads he visited he was informed the practice was to record as an engine failure any defect in the engine which resulted in a loss of time of two minutes and upwards to a passenger train, and ten minutes and upwards to a goods train.

The conclusion he arrived at was that, notwithstanding the size to which the modern American locomotive boiler had grown, the requirements of traffic were constantly outgrowing them. The boilers were "forced" to meet these requirements, and to this he thought might be attributed the leaky tube-troubles and not to the material used for the construction of the fire-boxes.

Mr. R. F. Trevithick wrote that the author stated (page 166), "when standing, there is considerable waste in the wide grates as compared with the narrow." The exact meaning of the statement did not appear to the writer quite clear. It might mean that, area for area, a wide grate was more wasteful than a long narrow one. If that were not so, it lost much of its point, for obviously a wide grate of 44 square feet would waste more fuel than a long narrow one of 30 square feet should the respective engines be kept waiting about. In fact a large boiler, such as would probably require a large grate, was more wasteful of fuel all round than a smaller one, both in getting up steam and maintaining it, that is, until its steam generating power was being utilised.

(Mr. R. F. Trevithick.)

The remarks as to the necessity of providing ample space for the proper circulation of water were much to the point. Having had to design an engine with 18-inch by 22-inch cylinders and 43-inch diameter coupled wheels, exception was taken to the design because the boiler had only 1186·48 square feet heating surface as against 1,231 square feet heating surface of a boiler for an engine with 18-inch by 22-inch cylinders and 48-inch diameter coupled wheels. The boiler with the smaller heating surface was the larger of the two and turned out to be a capital steamer, although it had to supply steam to cylinders whose cubic capacity per unit of linear advance, as compared with that of those supplied by the boiler with a larger heating surface, was in the respective proportion of 165·77 to 148·5. By the simple expedient of pitching the $1\frac{3}{4}$-inch diameter tubes $2\frac{3}{8}$-inch in place of $2\frac{1}{2}$-inch, more than 1,231 square feet of heating surface could have been obtained, but it was questionable if the boilers would have been improved by the change.

The author mentioned the gradual extension of the practice of making the top of the fire-box casing flat, and said "that the flat top has the important advantage of increasing the area of the water line at the hottest part of the boiler." That no doubt was the case; but he thought the flat top fire-box, or Belpaire fire-box, had an even more important advantage over the round top casing than that of affording a larger water surface, namely, that of being the correct form to resist internal pressure without deformation when direct staying was employed. With the advent of long fire-boxes and high pressures, the practice of using girder stays for the fire-box tops appeared with reason to be giving way to that of direct staying between crown of inside box and outside shell. The round top casing, connected by direct staying with the inside fire-box, when under pressure flattened out more or less on the top, and bulged at the sides between fire-box side stays and roof stays, and the larger its diameter and the higher the pressure the more unpleasant the distortion appeared. Assuming that the riveting was properly proportioned, the writer thought it probable a round top boiler of large diameter with direct staying would, if tested to destruction, fail somewhere about the outside casing, should supplementary

Japan Government Railways.

FIG. 52.—*Steam Test of Boiler (with two rows of sling stays) for new 6 W.C. Tank Engine, No.* 521.

Bulging, elongation and expansion due to 150 lbs. pressure.

Cross-stays were placed as nearly as possible half-way between the points where outside rows of vertical stays pass through shell and the points where top rows of horizontal side-stays pass through shell.

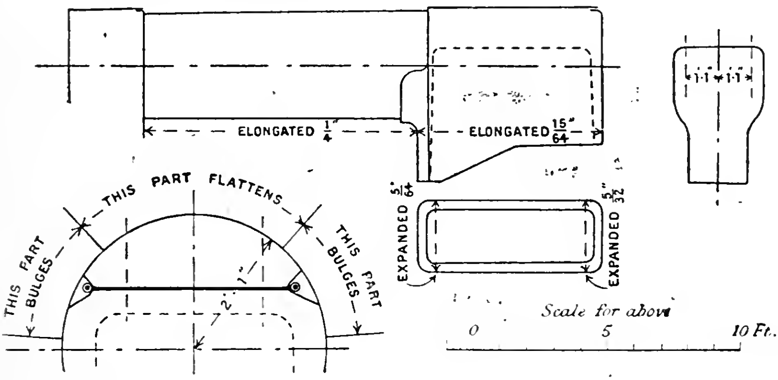
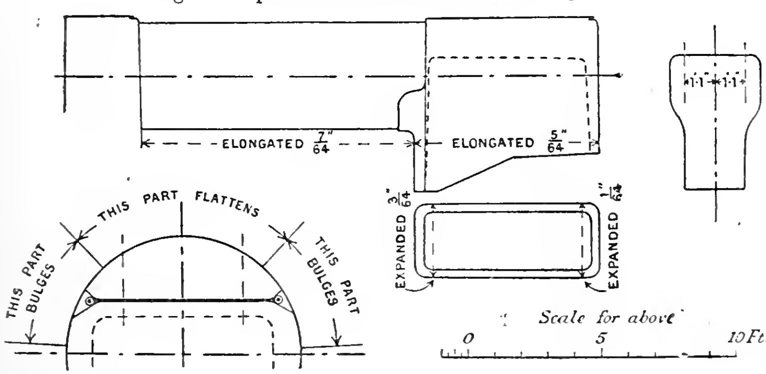


FIG. 53.—*Water Test of the same Boiler.*

Change in shape and dimensions due to 200 lbs. pressure.



(Mr. R. F. Trevithick.)

staying be omitted. There were of course various expedients for partially, if not entirely, counteracting the above referred to tendency to become distorted, but it was manifest that a shape which had no tendency to alter its form under pressure was preferable to one which had.

The objection to the Belpaire fire-box, from the point of view of those who might be responsible for boiler construction in shops where all flanging had to be done by hand, consisted in the difficult flanging work which had to be put in on the plate joining the box to the barrel. Having been confronted with this difficulty on several occasions, he then considered the adoption of the round top fire-box involved the lesser of two evils, and with the object of providing against distortion of form placed $1\frac{1}{4}$-inch diameter cross-stays over the fire-box, spaced $12\frac{1}{2}$ inches apart. The accompanying illustrations, Figs. 52 and 53 (page 253), showed result, which he thought was satisfactory to the extent that the distortion was not of a nature to cause any misgiving as to the boiler's suitability for a working pressure of 160 lbs. The inside radius of the round top of boiler shown in the illustration was 2 feet 1 inch, and the width of the sheet forming the outside casing 6 feet 5 inches.

Mr. C. HUMPHREY WINGFIELD wrote that he noticed the American boilers shown in the author's diagrams were in no case fitted with rings round their fire-holes, the plates being suitably dished instead. Out of sixteen English boilers, however, three were not dished and nine were fitted with fire-hole rings. His own experience, with boilers of this type worked under forced draught in torpedo-boats, was that leakage was rather apt to occur at the fire-hole if fitted with a ring, but that the plan shown in Fig. 10, Plate 23, obviated this. The arrangement shown in Fig. 11, Plate 24, was found to require the protection of a cast-iron ring just inside the fire-hole, so as to screen the rivet-heads from the fire ; otherwise leaks sometimes made their appearance.

With the wide fire-boxes used in torpedo-boats before the introduction of water-tube boilers, leakage at the tubes would always follow carelessness with regard to keeping the grate

covered. Increasing the distance between the fire-bridge and the tube-plate reduced this and, when the bridge was as much as 27 inches away, the trouble became unimportant in the hands of a good stoker. He fully agreed with the author as to the great importance of proper arrangements to regularise the circulation.

He would like to suggest that if the author could get tests of the stays (which broke with a tap of a hammer although apparently ductile when afterwards bent) made by the shock test carried out by Captain Sankey for the Alloys Research Committee,* the results could not fail to be of the greatest interest, and would probably throw light on the nature of the molecular change which had taken place.

Could the author say anything about the life of stays at the sides of large fire-boxes and the distribution of those which proved most liable to fracture? In some locomotives they appeared to break from a succession of bends backwards and forwards along lines roughly radiating from the centre of the bottom fire-box ring. He would like to know if this was the author's experience.

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* Proceedings 1904, Part 1, page 160.

The Institution of Mechanical Engineers.

PROCEEDINGS.

April 1906.

An Ordinary General Meeting was held at the Institution on Friday, 27th April 1906, at Eight o'clock p.m.: Edward P. Martin, Esq., President, in the chair.

The President said he was sure the Members would hear with deep regret of the death of their former esteemed Secretary, Mr. William P. Marshall. He had been a Member of the Institution for almost fifty-nine years, having been elected in October 1847, and for no less than twenty-nine years of which he had filled the office of Secretary, with great credit to himself and very much benefit to the Institution. The Council, at their meeting today, had unanimously decided to send a letter of condolence to his family, which action he was sure the Members would support.

The Minutes of the previous Meeting were read and confirmed.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following sixty candidates were found to be duly elected:—

MEMBERS.

Burn, Arthur James Horsfield,	Llanelly.
Davids, Smith William,	Nelson, Queensland.
Grindley, John Henry,	Liverpool.
Johnson, Henry Theophilus,	London.

Kirk, John William, ...	Akassa, Nigeria.
Moberly, James Edward, . . .	Newark.
Sheldon, Joseph, ...	Sheffield.
Simms, Frederick Richard, . . .	London.
Whiteside, Richard Fletcher, . .	Liverpool.

ASSOCIATE MEMBERS.

Beale, Samuel Richard, ...	Glasgow.
Boreham, George Henry, . . .	London.
Brookhouse, Frederick Henry, . .	Nottingham.
Chew, Leuig, ...	London.
Clark, Leonard Knight, ...	London.
Cliff, Thomas Percy Barlow, . . .	Malta.
Davidson, Alexander Elliott, Lieut. R.E., .	Chatham.
Fleet, Ernest Frank, ...	York.
Goodeve, Thomas Edward, . . .	Crewe.
Gordon, Ernest Arthur Hamilton, . .	London.
Gowing, Edward Charles, . . .	Stoke-on-Trent.
Greenhough, Edward Laurence, . .	Crewe.
Hemmings, Henry Francis Lewis, . .	Birmingham.
Johnson, Percy Stuart, ...	Birmingham.
Lithgoe, John, ...	Manchester.
Macauley, Charles Ridgeway, . .	London.
Mace, Francis Robens, ...	Durban.
Mawson, Robert, ...	West Lynn, Mass.
May, Thomas Arthur Pratt, . . .	Tientsin.
McBride, Frederick, ...	Truro.
McNicoll, Walter, ...	Dundee.
Moody-Stuart, Alexander, . . .	Motherwell.
Nutter, Harold Norman, . . .	Bradford.
Page, John Harper, ...	Dudley.
Peet, Henry Charles, ...	Leicester.
Pocock, Harold Francis, Engineer-Lieut. R.N., ...	2nd Cruiser Squadron.
Rhodes, Edgar, ...	Leeds.
Shepherd, James Whaley, . . .	Madras.

Smythe, Alan Theodore, . . .	London.
Sommerville, Alfred, ...	Paisley.
Sumner, George Geoffry, . . .	Manchester.
Trafford, Joseph Peter, . . .	Langley Green.
Watts, Herbert Willie, . . .	Weybridge.
Wedekind, Julius Edward, . . .	London.
Wyatt, Arthur James Hervey, . .	London.

GRADUATES.

Aitken, Arthur James, ...	London.
Allison, Walter Edward, . . .	Glasgow.
Bell, John, ...	Bradford.
Bishop, Reginald, ...	London.
Burr, Edmund Godfrey, ...	London.
Cooper, Albert George Warner Inerd, .	Cardiff.
Curtis, Vladimir, ...	Lincoln.
Donnithorne, Vyvyan Henry, . . .	Sunderland.
Forbes, Arthur, ...	London.
Gritton, Stanley Evan, ...	London.
Haan, Peter de, ...	Lincoln.
Lee, Joseph Standish Searchfield, . .	London.
Lemerle, Augustus Louis, . . .	London.
MacDonald, William Robinson, . .	Dundee.
McQuhae, William, ...	Workington.
Wickham, Oliver, ...	London.

The President announced that the following four Transferences had been made by the Council since the last Meeting:—

Associate Members to Members.

Binns, Walter, ...	Reading.
Moon, James George, ...	Birmingham.
Warden-Stevens, Fredric J., . . .	London.
Wilson, Alexander Cowan, . . .	Birkenhead.

The President said the members were aware that there were few things which had brought the Institution more to the front than the great and important work it had done for many years past in matters of research. He was pleased to be able to state that the Council, looking at the condition of the funds and at the prosperity of the Institution, had asked him to announce that they will be glad to have suggestions from the members as to subjects of research, as they are of opinion that further work in this direction might be undertaken by the Institution. Suggestions should be in the hands of the Secretary by the 1st of August. In addition to making the announcement that evening, a circular would in due course be placed in the hands of the members, enquiring what field of research could be best followed up by the Institution.

The following Paper was read and discussed:—

"Petroleum Fuel in Locomotives on the Tehuantepec National Railroad of Mexico"; by Mr. Louis Greaven, *Member*, of Buenos Aires.

The Meeting terminated at Half-past Nine o'clock. The attendance was 96 Members and 40 Visitors.

ANNIVERSARY DINNER.

The Anniversary Dinner of the Institution was held at the Hotel Cecil, Strand, London, on Thursday evening, 26th April 1906. The President occupied the chair; and the following were among the Guests who accepted the invitations sent to them, although those to whose name an asterisk (*) is prefixed were unavoidably prevented at the last from being present:—

*The Right Hon. Lord Stalbridge, Chairman of the London and North Western Railway; The Hon. Mr. Justice Darling; Major-General D. D. T. O'Callaghan, C.V.O., President of the Ordnance Committee; Sir James Kitson, Bart., M.P.; *Sir David Dale, Bart.; Sir Francis Mowatt, G.C.B., I.S.O.; Sir William H. M. Christie, K.C.B., Astronomer Royal; Captain Sir G. R. Vyvyan, K.C.M.G., R.N.R., Deputy Master of the Trinity House; Colonel Sir Charles M. Watson, K.C.M.G.; Sir R. Melvill Beachcroft, Chairman of the Metropolitan Water Board; *Sir Myles Fenton, Chairman of the Rhymney Railway; Sir Henry Tanner, I.S.O., H.M. Office of Works; Major-General F. W. Benson, C.B., Director of Transports and Remounts; Professor Thomas E. Thorpe, C.B., LL.D., F.R.S., Director of Government Laboratories; *Lieut.-Colonel H. A. Yorke, C.B., R.E., Chief Inspecting Officer, Board of Trade; Mr. E. Grant Burls, C.S.I., Director-General of Stores, India Office; *Mr. Alfred Baldwin, M.P., Chairman of the Great Western Railway; Professor J. A. Ewing, F.R.S., Director of Naval Education; Mr. J. H. Hillier, H.M. Office of Works; Colonel H. C. L. Holden, F.R.S., Superintendent of the Royal Gun Factory, Woolwich; Major P. A. MacMahon, Superintendent of the Standards Department, Board of Trade; Mr. E. G. Rivers, I.S.O., Chief Engineer, H.M. Office of Works; *Mr. Peter Samson, Engineer-in-Chief, Marine Department, Board of Trade; Lieut.-Colonel P. G. Von Donop, R.E., Chief Inspecting Officer, Board of Trade.

Agents-General for the Colonies: *Sir Thomas E. Fuller, K.C.M.G. (Cape of Good Hope); *The Hon. Sir Horace Tozer, K.C.M.G. (Queensland); *The Hon. Sir William Arbuckle (Natal)

The Hon. Alfred Dobson, C.M.G. (Tasmania); *Mr. T. A. Coghlan, I.S.O. (New South Wales); Mr. W. H. James, K.C. (Western Australia); The Hon. J. G. Jenkins (South Australia); *The Hon. J. W. Taverner (Victoria).

Ordnance Committee: Captain A. H. Limpus, R.N.; Lieut.-Colonel L. T. Pease, R.M.A.; Captain Morgan Singer, R.N.; Lieut.-Colonel A. M. Stuart, R.E.; Major S. M. Renny, R.A.

Technical Institutions: Sir Alexander Binnie, President of the Institution of Civil Engineers; *Mr. Robert A. Hadfield, President of the Iron and Steel Institute; Mr. John Gavey, C.B., President of the Institution of Electrical Engineers; Mr. Charles Bidwell, President of the Surveyors' Institution; Mr. Dugald Clerk, President of the Junior Institution of Engineers; Mr. T. H. Deakin, President of the South Wales Institute of Engineers; Mr. W. Henry Hunter, President of the Manchester Association of Engineers; *Professor John Perry, F.R.S., President of the Physical Society; Mr. Maurice Wilson, President of the Society of Engineers; Mr. Charles Wood, President of the Institution of Gas Engineers; *Dr. J. H. T. Tudsbery, Secretary of the Institution of Civil Engineers.

Mr. J. D. Bonner; *Mr. R. A. Bruce; Dr. H. C. H. Carpenter; Mr. F. W. Ellis, Institution Treasurer; Dr. R. T. Glazebrook, F.R.S., Director of the National Physical Laboratory; Mr. F. W. Harbord, F.I.C.; *Mr. J. C. Inglis, General Manager of the Great Western Railway; Mr. C. Kadono; Mr. Henry W. Martin; Mr. R. A. McLean, Institution Auditor; Mr. John B. Millar, Master of the Grocers' Company; Mr. L. Pendred; Professor W. Cawthorne Unwin, F.R.S., Honorary Member; Mr. Septimus Vaughan-Morgan.

Executive Committee for Cardiff Meeting: *Sir William T. Lewis, Bart., Chairman; *Alderman Robert Hughes, Lord Mayor; *Mr. A. Beasley; Mr. E. Dawson; Mr. William Evans; *Mr. Robert Forrest; *Principal E. H. Griffiths; Sir John Gunn; Mr. E. M. Hann; Mr. Enoch James; *Mr. J. Arthur Jones; *Mr. John Macaulay; *Mr. Ernest A. Prosser; *Mr. T. Hurry Riches and Mr. David E. Roberts, Honorary Local Secretaries.

The President was supported by the following Members of the Council:—*Past-Presidents*: Mr. William H. Maw; Mr. E. Windsor

Richards; *Mr. Percy G. B. Westmacott; and Sir William H. White, K.C.B., LL.D., F.R.S. *Vice-Presidents:* Mr. John A. F. Aspinall; *Mr. Edward B. Ellington; Mr. Arthur Keen; *Sir William T. Lewis, Bart.; *Mr. T. Hurry Riches; and *Mr. A. Tannett-Walker. *Members of Council:* Mr. George J. Churchward; Mr. H. F. Donaldson; Mr. Graham Harris; Dr. Edward Hopkinson; Mr. J. Rossiter Hoyle; Mr. Michael Longridge; Mr. John F. Robinson; Mr. Mark Robinson; and Mr. James Rowan.

After the President had proposed the loyal toasts, Sir James Kitson, Bart, proposed that of "Our National Defenders," which was acknowledged by Major-General D. D. T. O'Callaghan, C.V.O., President of the Ordnance Committee.

The toast of "Kindred Societies" was proposed by Sir Francis Mowatt, G.C.B., I.S.O., who alluded with satisfaction to the reports presented by the Committee on the Royal College of Science and School of Mines and the Committee on the Education of Engineers. The recommendation of the first of these committees had been accepted by the Government, and the generous support promised by various public bodies had enabled the committee to draw up a scheme for the establishment of an Imperial Central College of Technology and Applied Science, which would be under the control of a body thoroughly representative of the various interests concerned, and in close touch with the scientific requirements of the age. The funds now available would not of course suffice for the Institution as it would ultimately develop, but they would enable an immediate and substantial beginning to be made, the effects of which would very soon make themselves felt. With regard to the second committee, over which Sir William White had presided, it had provided a scheme for the education of engineers, and he hoped it would be accepted. He believed that the outcome of the two schemes would be the provision of an education which would uphold the old pre-eminence of English engineers.

Sir Alexander Binnie, President of the Institution of Civil Engineers, in reply, said that the engineering profession as a whole

(Sir Alexander Binnie.)
were all working to solve one great problem—the application of science to the use and convenience of mankind.

Mr. John A. F. Aspinall, Vice-President, proposed the toast of "Our Guests," which was acknowledged by Sir William H. White, K.C.B., LL.D., F.R.S., Past-President, who said that the value of education to the engineer could not be over-estimated. For a long period in this country, the value of scientific methods had not been realized as it should have been, but now the nation was awake, which explained the movement to which Sir Francis Mowatt had alluded. The committee, over which he himself had had the honour to preside, represented for the first time in British engineering, the association of all the principal engineering societies in a matter of radical importance, and it should always be remembered that the suggestion for that joint action was made by the Council of the Institution of Mechanical Engineers. The idea at the root of the report was that mechanical engineering must be at the bottom of all engineering, and there was a recommendation that each engineer, whether civil, mining, metallurgical, marine, electrical, or gas, should, before he began his college training, have at least a year or two in mechanical engineering workshops.

The toast of "The Institution of Mechanical Engineers," was proposed by the Hon. Mr. Justice Darling, and was acknowledged by the President, who stated that the membership continued to grow and numbered nearly 5000 members. As a body they were carrying on researches on alloys of copper and aluminium at the National Physical Laboratory, on gas-engines of a large size at Birmingham University, and on steam-engines at Edinburgh University.

PETROLEUM FUEL IN LOCOMOTIVES ON THE TEHUANTEPEC NATIONAL RAILROAD OF MEXICO.

By Mr. LOUIS GREAVEN, *Member*, of Buenos Aires;
late Locomotive and Car Superintendent,
National Railway of Tehuantepec.

The cost of Fuel is a matter of such great importance in the economy of railway operation that the author hopes the following remarks and data, compiled after careful observation of the actual results obtained by the use of liquid fuel for one year on the Tehuantepec National Railroad of Mexico, may be of interest.

Ports and Railroad.—The vast works undertaken by the engineering and contracting firm of Sir Weetman Pearson and Son, of London, namely, of constructing a port capable of receiving ocean-going steamers at Coatzacoalcos on the Gulf of Mexico, another port of similar capacity at Salina Cruz on the Pacific Ocean, and connecting both ports by means of a solidly built 4-foot 8½-inch gauge railway equipped with all modern appliances, and operating all in partnership with the Mexican Government, are undoubtedly familiar to the members of the Institution.

Pioneer Oil-burning in Mexico.—That this firm, however, should be the pioneer in fuel oil-burning in Mexico, a country which bids fair to become one of the oil-producing countries in the world in the near future, may possibly not be generally known, and the results obtained from their enterprise is full of interest for many.

Fuel in Mexico.—The fuel question in Mexico has always been a very serious one for railroads and industrial establishments, in consequence of there being no coal produced in the country, with the exception of a small quantity of inferior quality in the most northern State, and also in view of the ever-increasing cost of firewood and the growing difficulties experienced in obtaining it.

Water-Power; Oil Wells.—The serious aspect of the fuel question has led to two very good and useful results, first the development of a vast number of waterfalls throughout the country for power, principally electrically transmitted, and second, the development of the exploration for oil. Powerful companies have been organised for the purpose of prospecting and developing the oil-bearing regions, and the firm of Messrs. Pearson and Son is perhaps the most deeply interested in this particular industry. Preferably to awaiting the full development of the Mexican oil-wells, the latter firm wisely determined to commence operations with oil-fuel imported from Beaumont, Texas, not only because preliminary trials showed the economy obtained by its use, but also in order that the entire railroad system might be equipped for the use of oil-fuel when available from Mexican wells, the ultimate certainty of which was proved to be beyond doubt by the explorations made and trial wells already drilled.

Oil-Tankage.—In pursuance of this policy a large storage-tank was erected at the railroad terminal of Coatzacoalcos, having a capacity of 35,000 barrels of 42 United States gallons (35 Br. gals.) each,* and auxiliary tanks each having a capacity of 28,200 gallons

* 1 U.S. gallon = 231 cub. in. 1 Brit. gallon = 277·27 cub. in. United States gallon = $\frac{5}{6}$ British Imperial gallon.

(23,500 Br. gals.) were erected at the following stations for supplying engines on the road :—

Mile post	79, Santa Lucrecia	1 tank.
,, ,,	127, Rincón Antonio	2 tanks.
,, ,,	193, Salina Cruz	1 tank.

The details of these tanks are as follows :—

Storage Tank at Coatzacoalcos.—The construction is circular and consists of six tiers of steel plates riveted together, with a steel-plate floor. This tank is erected at a distance of 400 yards from the wharf side where it is intended that ships will lie, and on an elevation or hill, the bottom of the tank being 20 feet above rail-level. The dimensions are given in Table 1, and the cost of tank-equipment and installation in Table 3 (page 269).

TABLE 1.—*Dimensions of Storage Tank at Coatzacoalcos.*

Thickness of plates, Tank floor	$\frac{9}{16}$ inch.
,, ,, Bottom tier	$\frac{9}{16}$,,
,, ,, Second ,,	$\frac{1}{2}$,,
,, ,, Third ,,	$\frac{7}{16}$,,
,, ,, Fourth ,,	$\frac{3}{8}$,,
,, ,, Fifth ,,	$\frac{5}{16}$,,
,, ,, Sixth ,,	$\frac{1}{4}$,,
,, ,, Roof	$\frac{3}{16}$,,
Height of tank	$29\frac{3}{4}$ feet
Inside diameter at half height of tank	92 ,,
Capacity in barrels (42 U.S. gallons)	35,203
Contents in U.S. gallons	1,478,543
,, ,, British gallons	(1,232,119)
Average barrels per foot of height	1,183
Average gallons (U.S.)	49,695
,, ,, (British)	(41,413)

TABLE 2.—*Dimensions of Auxiliary Tanks.*

Thickness of plates, Tank floor	$\frac{3}{8}$ inch.
,, ,, Bottom tier	$\frac{3}{8}$,,
,, ,, Second ,,	$\frac{5}{16}$,,
,, ,, Third ,,	$\frac{1}{4}$,,
Capacity in barrels (42 U.S. gallons	671
Capacity in U.S. gallons ,, ,, British gallons	28,200 (23,500)
Capacity in barrels per foot of height	56
Capacity in gallons (U.S.) ,, ,, ,, (British)	2,350 (1,958)

The station or outside auxiliary tanks are 20 feet diameter and 12 feet high, of steel plates riveted together. The dimensions of these tanks are given in Table 2.

There are also six travelling steel oil-tank cars, with a capacity of 6,600 U.S. gallons (5,500 Br. gals.) each, used for transporting the oil from the general storage tank at Coatzacoalcos to the auxiliary tanks on the road.

While the storage tanks were being erected, orders were placed with the locomotive builders for the necessary appliances to convert coal and wood-burning engines into oil-burners, and some new engines, which were under construction, were built as oil-burners, Plates 35 to 38.

When the tanks were finished, they were tested for leakages by being filled with water, and any defects were repaired. Notwithstanding this, when subsequently filled with oil several filtrations were observed, and it was demonstrated that while a tank might be perfectly water-tight, it was not necessarily oil-tight, and that further repairs were necessary.

The tanks having been completed and new oil-burning engines received, an order was placed in Beaumont, Texas, for the first consignment of fuel oil. This was received in the oil-steamer "Northtown" and oil-barge "Gusher," which contained 21,833 and

TABLE 3.

*Cost of Tank-Equipment and Installation.**

	Dollars.	£
	U.S. Gold.	
35,000-barrel storage tank at Coatzacoalcos .	$7,800·00	1,560
	Mexican silver.	
Cost in Coatzacoalcos	$21,913·00	1,826
Erection, contract price	9,000·00	750
Extras, carrying materials to ground, ropes and appliances supplied, wood floor under tank, straightening plates which were badly bent, painting, levelling ground, and time lost waiting for materials	4,679·67	390
Total cost of erection	$13,679·67	1,140
Total cost of Tank erected	$35,592·67	2,966
Four 28,000-gallon (23,333 Br. gal.) tanks cost in United States $1,925·00 gold each . .	$7,700·00	1,540
One 28,000-gallon tank cost in station . .	$5,461·00	455
Erection, contract price	600·00	50
Foundations and extras	375·00	31
	$6,436·00	536
Six travelling oil-tank cars 6,600 U.S. gallons each.		
Cost of each on railway	$2815·00	234
Total cost of storage and travelling tanks . .	$78,226·67	6,519
Cost of 400 yards 4-inch line pipe from wharf to tank	$2,600·00	216
Cost of valves for same	70·00	6

* The costs are given in Mexican silver currency or U.S. gold, the exchange ruling at the time this equipment was installed being 245 on New York and 20⅜ on London. A Mexican dollar has been assumed equal to 1*s*. 8*d*., and a U.S. gold dollar equal to 4*s*. 0*d*.

TABLE 4.

Converting Coal-Burning Engines. Cost of Converting a Coal-Burning Engine into an Oil-Burner.

	$	£
Fire-brick and labour of setting	70·00	6
New ash-pan, fire door, and labour	96·02	8
Burner, piping, fittings and labour	304·35	25
Oil tank, 1,200 gallons, and fitting in tender .	775·00	65
Incidental expenses and supervision	165·63	14
	1,411·00	118

6,738·7 barrels respectively, the barge being towed by the steamer from Port Arthur, Texas, to Coatzacoalcos. It may be here remarked that the barge was necessary for lightering, as the Port of Coatzacoalcos not having then been finished, a fully-laden steamer drawing 24 feet of water could not enter the port. The oil was, therefore, first pumped out of the barge into the storage tank, and then the steamer cargo was lightered by the same barge until the whole quantity was pumped ashore. In a very short time steamers of heavy draught will not only be able to enter this port, but to make fast to the new steel wharfs, and all lighterage will be avoided.

Pumping Oil ashore.—Unless the steamer can enter a port and pump the oil ashore by means of its own pumps, it is always preferable to charter a barge already fitted with its own steam-pump, to which steam can be supplied by the tug which tows the barge to and from the steamer, or by a stationary boiler situated on the shore. The pumps are generally double-acting, 6 or 8 inches diameter. It is also advisable that the oil-steamer and barge should provide suitable flexible hose to make the connection between the oil-tanks on board and the land pipe-line. Unless the above arrangements are made, the receivers of the oil will have to furnish a steam-boiler and pump near the wharf and the flexible connection to connect up on board, and special care should be taken to ascertain that the connecting couplings are of the right size and correct pitch of thread.

Any neglect in these respects is liable to cause demurrage after the oil-boat has entered port.

If it is provided that the oil-barge shall use its own pumps, then arrangements must be made for the supply of steam either from a tug-boat or from a boiler on land. Of course, if a steamer can go alongside a wharf it supplies its own steam, but oil-barges do not carry steam-boilers as a rule. In some cases a submarine pipe-line is laid, the land end being connected to the land pipe-line, and the sea end to an anchored buoy, which end is picked up and connected to the outlet pipe of the steamer when necessary; this arrangement obviates the necessity of the oil-steamer entering the port. The first and subsequent consignments of oil were pumped through a 4-inch pipe-line (subsequently increased to $6\frac{1}{2}$ inches) 400 yards long, to an elevation of 50 feet above rail-level, this being the top of the storage tank, allowing 30 feet for the tank and 20 feet for the elevation of the hill on which it was erected. This oil was pumped by the pump belonging to the oil-barge at the rate of 300 barrels per hour, day and night, until the complete cargo was transferred to the storage tank, the pumping having begun on 17th March 1904, and finished on the fourth day.

The oil was purchased from the Higgins Oil and Fuel Co., Beaumont, Texas, and the cost and expenses were as shown in Table 5 (page 272):—

The cost at Rincón Antonio, where the railroad shops and general offices are situated, mile post 127, was \$2·637 (4*s.* 5*d.*) per barrel, the additional price being made up of freight charges from Coatzacoalcos to Rincón Antonio and cost of pumping into station tanks. For the purposes of this calculation, it was carefully ascertained that two-thirds of the oil consumed by locomotives was drawn from Coatzacoalcos storage tank direct by engines and one-third at Rincón Antonio. The tanks at Santa Lucrecia and Salina Cruz, mile posts 79 and 193 respectively, were not in use at the time, consequently the average cost per barrel may be taken at \$2·187 (3*s.* 8*d.*) as shown by the following formula $\$1 \cdot 962 \times 2 + \$2 \cdot 637 \div 3 = \$2 \cdot 187$; however, stores charges for superintendence, etc., brought the issuing price to \$2·52 (4*s.* 2*d.*) per barrel.

TABLE 5.—*Cost of Oil.*

	Per Barrel. Mexican Silver.	Per Barrel.
	$	s. d.
Cost per barrel of oil	1·1042	1 10
Telegrams in connection with purchase .	0·0015	0 0·03
Commissions	0·005187	0 0·10
Insurance	0·0249	0 0·5
Purchasing Agent's expenses	0·081367	0 1·63
Freight, Lighterage and Handling . .	0·61	1 0·2
Port dues, Pilots, and Fuel for Steam-Pump	0·09419	0 2
Labour in connection with pumping ashore.	0·005455	0 0·11
Superintendence and incidental expenses .	0·035201	0 0·7
Cost per barrel of 42 U.S. gallons at Coatzacoalcos, not including interest on capital invested in installation of tanks and in oil	1·962	3 3¼

Supplying Oil to Engines.—For the purpose of supplying engines and filling travelling tank-cars, the large storage-tank at Coatzacoalcos is fitted with an 8-inch diameter valve, from which is run a main of equal size a distance of 100 yards to a low-lying or basin-shaped ground, and a second valve is provided at the extreme end of this main. The main runs through the station yard, and at a suitable point a branch is taken off to a stand-pipe or column, which is provided with a 6-inch valve, and engines are supplied with oil, and tank-cars filled at this column in much the same way as engine tanks are supplied with water. The object of the 8-inch main being carried out of the station yard to low-lying or basin-shaped ground beyond, and fitted with a valve at the extreme end, is to provide a means for allowing the oil to escape from the tank in case it took fire from lightning, or from any other possible

cause. The main valve at the tank is always open, and the outlet is controlled by the valve at the end of main and the stand-pipe valve. The tank being elevated above rail-level, the engine and travelling tank-cars are supplied with oil by gravity. Engines are supplied with oil from auxiliary station-tanks in much the same way as water; a spout (4 or 6 inches in diameter) from the tank lifts and lowers by means of counterweights and knuckle-joints. It is very necessary to keep these joints properly ground in and oil-tight. Leather or rubber hose fixed at the end of the spouts is not suitable, as it drips too much and the petroleum rots it quickly. There is a valve inside the oil-tank, with a lever on top and a rod or chain outside the same, as is usual with a water-tank.

Pumping Oil into Station Tanks.—In some parts of the United States inclined tracks are constructed alongside station oil-tanks similar to inclined tracks at coal bins; the travelling cars are run up the incline and emptied by gravity into the station tank. Another system also sometimes adopted is to construct a reservoir under the ground level into which the oil-cars are emptied, and the oil is subsequently pumped into the station tank at leisure. For large railroad systems these plans are undoubtedly the most efficient and economical, but the considerable expense was not considered justified or necessary at the time on the Tehuantepec Railroad.

A flat car was therefore fitted up with a 6-inch double-action pump and vertical boiler, the pump being provided with suitable piping and flexible hose to connect with the discharge pipes of tank-cars, and to deliver the oil into station tanks. At Rincón Antonio, where the railroad company's shops are situated, an electric pump is provided for this purpose driven by the current from the generators which provide power for the shop tools and machinery, the entire works being operated by means of electric motors.

The capacity of oil-tanks on the tenders of some oil-burning engines is at present provided as follows, a few engines of different types being given in Table 6:—

TABLE 6.

Capacity of Tender Oil-Tanks.

Engine Nos.	Class of Engines.	No. of Engines.	Capacity of Tank.		Average per inch.	
			U.S. gallons.	British gallons.	U.S. gallons.	British gallons.
15–16	10 wheels	2	1,200	1,000	20·24	16·86
21	8 wheels	1	1,200	1,000	21·82	18·18
60–67	consolidation	8	1,200	1,000	19·00	15·83
68–71	,,	4	1,987	1,656	73·60	61·33
40–43	10 wheels	4	3,000	2,500	47·00	39·13
30–32	10 ,,	3	1,976	1,747	—	—

Table 7 shows the fuel weight-carrying capacity of the foregoing engines as coal-burners and oil-burners, also the distance attainable under ordinary circumstances, with a full tank of both classes of fuel.

The weight of a gallon of fuel oil is 7½ lbs.

TABLE 7.

Comparative Capacities of Oil- and Coal-Burning Locomotives.

Engine Nos.	Capacity of Coal.	Capacity of Oil.	Engine-Miles to tank of oil.	Engine-Miles to bunker of coal.	Service of Engine.
	Lbs.	Lbs.			
15–16	7,840	9,000	133·3	87·5	Freight
21	10,080	9,000	263·15	244·3	Passenger
60–67	11,200	9,000	133·3	125	Freight
68–71	—	14,902	220·7	—	,,
40–43	—	22,500	333·3	—	,,
40–43	—	22,500	657·8	—	Passenger
30–32	13,440	14,822	219·5	150	Freight

Note.—Engines Nos. 68–71 and 40–43 were built as oil-burners; the other engines were converted.

TABLE 8.

Comparative Consumption and Cost of Oil with Coal and Wood.

Trains.	Oil.			Coal.			Wood.	
	Average consumption per Engine-Mile.	Engine-Miles per Barrel (42 gals.).	Train-Miles per Barrel (42 gals.).	Average consumption per Engine-Mile.	Engine-Miles per Ton (2,240 lbs.).	Train-Miles per Ton (2,240 lbs.).	Average consumption per Engine-Mile.	Train-Miles per Tarrea (72 cub. ft.).
	Gals. (Lbs.)	Miles.	Miles.	Lbs.	Miles.	Miles.	Tarreas. (Cub. ft.)	Miles.
Passenger	4·56 (34·2)	9·2	8·7	41·25	54·3	52·6	0·087 (6·26)	10·4
Freight	9·00 (67·5)	4·7	4·4	89·6	25·0	22·0	0·151 (10·87)	6·3

Cost.						
	Per Engine-Mile.		Per Engine-Mile.		Per Engine-Mile.	
	Cents.	Pence.	Cents.	Pence.	Cents.	Pence.
Passenger	27·4	5·5	32·4	6·5	33·6	6·7
Freight	53·6	10·7	69·2	13·8	58·0	11·6

For priees charged for fuel, *see* Table 9 (pages 281–283).

Price of Oil and Coal.—Exception may be taken in the foregoing figures to the price charged for coal, but the price quoted is the exact amount at which the coal was issued; and if it is considered high in comparison with the issuing price of coal on other railroads, or in other places, it should be remembered that the coal was handled under expensive conditions, such as double or triple handling, and also lighterage, all of which difficulties were unavoidable under existing circumstances. For the same reasons the issuing price of oil is relatively high, and any improvement in facilities which would reduce the cost of coal would also tend to lower the cost of oil. Therefore, for comparative purposes the statement may be taken as correct.

Stationary Boilers and Oil Fuel.—Shortly after the initiation of oil fuel in the locomotive service, it was decided to convert the stationary boilers at the general workshops at Rincón Antonio from coal-burners into oil-burners. These boilers originally used wood, and subsequently coal, consequently the author has been able to observe the results obtained in the same boilers as wood-, coal-, and oil-burners. There are three boilers of tubular locomotive type, each of 400 square feet heating surface, or say 40 horse-power each, with wood and coal. The three boilers were formerly used together, but since the installation of oil fuel only two boilers are needed. The boilers supply steam for one 120-kw. generator, for a steam-hammer and one air-compressor, and the consumption of the different classes of fuel per month was as follows:—

	$	$	£
Wood, 313 tarreas (72 cubic feet each) . . @	3·83	1,198·79	100
Coal, 86 tons . . . . . @	17·00	1,462·00	122
Oil, 16,200 gallons . . . . . @	0·06	972·00	81

The present electrical output is 7,300 kw.-hours per month, or 9,785 HP.-hours per month, and the cost per HP.-hour is, therefore, ten cents silver, or four cents gold. In this price is of course included the steam used for the steam-hammer and air-compressor, the energy of which is not measured by the wattmeter.

The comparative statement is as follows:—

Cost of fuel per horse-power-hour—

		Pence.
Wood	12·2 cents silver	(2·4)
Coal	14·9 " "	(3·0)
Fuel oil	10·0 " "	(2·0)

Burners.—There are many kinds of hydro-carbon burners, Plate 35, and amongst those with which the author has had personal experience are the "Houlden," "Sheedy Carrick," "Booth," "Lahey," "Best," and others. One of the most essential points about a burner is the facility of keeping it clean and free from clogging; and another is its adjustability both for giving the right direction to the flame or spray, and regulating the proper proportionate supply of steam or compressed-air and oil. The author has found that the most satisfactory results in these respects, and in the greatest economy of oil fuel, were obtained with the "Best" burner, which is very easy of access and adjustment.

There are some incidental advantages in using oil fuel, apart from the question of consumption. All clinkers, ashes, sparks, falling fire and choking up of front ends of smoke-boxes, are obviated.

Cleaning Coal-burners.—The author has ascertained that the cleaning away of clinkers, ashes, the cleaning of front ends, smoke-boxes, and all such work incidental to a coal-burning engine before being put into the Round House costs on this railroad 78 cents silver (1*s.* 3½*d.*) each trip, and this does not cover the loss of time to the engine, which may be taken to amount to one hour per trip. This additional hour is taken advantage of for repairs, with an oil-burning engine, as none of the work mentioned above has to be done. Another advantage is the economy in freight on fuel and the liberating of coal-cars for other work or service.

The weight of a gallon of oil is 7½ lbs., and in freight service 1,687 lbs. of oil are shown to be equal to 2,240 lbs. of coal, while in passenger service 1,857 lbs. of oil are shown to be equal to 2,240 lbs. of coal. Now, as at least three-fourths of the consumption is in freight service, one can take—

$$\begin{aligned} 1{,}687 \text{ lbs.} \times 3 + 1{,}857 \text{ lbs.} &= 6{,}918 \text{ lbs. oil,} \\ 2{,}240 \text{ ,, } \times 4 &= 8{,}960 \text{ ,, coal,} \end{aligned}$$

or a saving in weight hauled of $22\frac{3}{4}$ per cent. if oil-burning engines take oil as frequently as coal-burners have to take coal.

The monthly consumption of coal by locomotives at Rincón Antonio was an average of 513,671 lbs., consequently the monthly saving of weight hauled would be 116,860 lbs., which is equal to $22\frac{3}{4}$ per cent., or 6,604 long ton-miles per month for the station of Rincón Antonio alone.

Another advantage of oil-burning engines is the facility and quickness with which steam can be raised in a locomotive. While it is not advisable to raise steam too quickly in any boiler in consequence of the sudden expansion of the plates being injurious, yet, at times it is necessary in railroad operation, and when necessary, steam can be got up in less than an hour, whereas $2\frac{1}{2}$ or $3\frac{1}{2}$ hours is the usual time for getting up steam with coal.

Another advantage is obvious: for instance, when an engine is detained for any reason on the road, or reaches its destination with orders to turn back after the enginemen and trainmen get rest, the fire can be extinguished during the time the engine is standing, there is therefore no consumption of fuel, while an engine in fair condition will always retain sufficient steam-pressure to start the burner after standing for several hours; any danger to the boiler or fire-box in consequence of water falling too low while the engine is standing is also obviated. A coal-burning engine will consume during a lay-over of ten hours 100 kg. (220 lbs.) of coal at least, which represents over \$1·70 (2*s.* 10*d.*) for which no useful return is obtained.

One of the most important points to observe in oil-burning boilers is the condition of the fire-brick work. Good fire-bricks and good bricklaying are very necessary; ordinary fire-bricks such as are used in furnaces are not always suitable, as the heat of the oil fire is very intense. Large blocks, Plates 35 to 37, should be used in the arch, and 9-inch by $4\frac{1}{2}$-inch by $2\frac{1}{2}$-inch blocks in the sides and front wall. With first-class materials and workmanship the brickwork in a locomotive may last a year without renewal.

Many inquiries have been made with regard to the wage cost of enginemen for oil-burners. The author has found that the conversion of coal-burners into oil-burners does not necessarily entail any alteration in the rate of pay of the enginemen, but inasmuch as coal and wood passers are dispensed with, the loading of coal and wood on engines is obviated and cleaning out of ash-pans unnecessary; these economies reduce the wage bill accordingly.

Effect of Oil on Life of Fire-boxes.—The author's experience, so far, does not indicate any detrimental effect or injury to fire-boxes; no leakages have been found either in the new engines or in the old, which have been converted from coal-burners. He is of opinion that, if the fire-brick work is very carefully looked after and kept in good repair, the injury to the fire-boxes, should any occur, will be reduced to a minimum. As the heat of an oil-fire is more intense than that of coal, the injurious effects on oil-burning fire-boxes may be greater than on coal-burning fire-boxes. Copper fire-boxes stand the excessive heat better than steel, in consequence of their greater adaptability to contraction and expansion. A slight distillation of the crude oil, where this is possible, eliminates to a considerable extent the deleterious effects of its combustion upon heated steel. The presence of sulphur in crude oil is of course liable to cause corrosion of fire-boxes, but if the percentage of sulphur is limited to, say, 2 per cent., the injury done is very little more than when burning coal.

The author's experience on this railroad has not yet been sufficient to enable him to give an opinion on the actual amount of detriment caused to fire-boxes attributable to fuel oil as compared with that attributable to coal, but during the twelve months that oil has been used, there have been no troubles with fire-boxes which can be attributed to the use of oil fuel.

Fire-boxes need greater care and attention when oil fuel is used, and a great deal depends on keeping the fire-brick work in sound condition. An engine should never be allowed to go out with a defective arch or a broken wall, and if proper care and attention are given, it is the author's opinion that the life of a fire-box of

an oil-burning engine is very little shorter than the life of that of a coal-burner.

None of the enginemen or firemen on their road had any experience in burning oil on locomotives, and yet no difficulty whatever was experienced in teaching them and inducing them to take an interest in the new fuel. With the assistance of a competent instructor brought from the International and Great Northern Railroad of Texas, most of their enginemen and firemen soon understood the handling of oil-burning locomotives; and the instructor stated that he found Mexican firemen very apt pupils, and he had no difficulty whatever in teaching them their duties.

Conversion of Engines.—The conversion of engines from coal or wood to oil-burners entails a considerable amount of work, and requires the construction of new ash-pans, brickwork, the application of burners, cocks, pipes, hose, and the fitting of the oil-tank and connections in the tender. The time required to convert an engine is from twelve to fifteen days, and the cost about $1,411 Mexican currency (£118), including materials, oil-tank, ash-pan, fire-brick, burner, pipes, connections, labour, supervision, freight, etc. *See* Table 4 (page 270).

Oil fuel has been adopted only to a limited extent on railroads in the United States; such railroads are located in the oil-well districts, and even then they have not adopted it to the exclusion of coal. It is also used in some parts of Europe, in Peru, and extensively in Russia, and the adoption of oil fuel by any railway will of course greatly depend on its location and on the price at which it can obtain coal. The production of oil fuel at present in the United States is not sufficient to enable the great trunk railroads to adopt it, and moreover, most of the railroad companies in the United States can obtain coal at such a low price that it is difficult for oil fuel to compete.

While only a few of the railroads, however, in the United States, principally those running through Texas and California, and the extreme West, can use oil economically, oil fuel has decidedly the advantage over coal for exportation and consequently for use in

(*Continued on page* 284.)

TABLE 9 (*continued to page 283*).

Comparative Statement of Performance of Locomotives.

For six months ending 31st December 1904.

OIL.

Month.	Engine-Miles.	Train-Miles.	Total Barrels.	Engine-Miles per Barrel.	Train-Miles per Barrel.	Cost per Engine-Mile.	Cost per Train-Mile.
PASSENGER SERVICE.							
						Pence.	Pence.
July	5,094	4,457	579	8·8	7·7	5·7	6·5
August	4,891	4,460	542	9·0	8·2	5·6	6·1
September	4,717	4,381	487	9·7	8·9	5·2	5·6
October	5,928	5,568	608	9·7	9·1	5·2	5·5
November	5,266	5,258	562	9·4	9·3	5·3	5·0
December	7,737	7,737	854	9·0	9·0	5·6	5·6
FREIGHT SERVICE.							
July	15,398	13,832	2,996	5·1	4·7	9·9	10·7
August	11,052	9,830	2,595	4·2	3·7	12·0	13·6
September	8,081	7,492	2,351	3·4	3·1	14·8	16·3
October	12,738	12,289	2,552	4·9	4·8	10·3	10·5
November	17,031	15,460	3,504	4·8	4·4	10·5	11·4
December	18,977	18,473	3,574	5·3	5·1	9·6	9·9
Totals and Average Mileage, Consumption, and Cost.							
PASSENGER.							
—	33,633	31,861	3,632	9·2	8·7	5·5	5·8
FREIGHT.							
—	83,277	77,376	17,572	4·7	4·4	10·7	11·4

(For Notes, *see* page 283.)

TABLE 9 (*continued on page* 283).

Comparative Statement of Performance of Locomotives.

For six months ending 31st December 1904.

COAL.

Month.	Engine-Miles.	Train-Miles.	Total Tons.	Engine-Miles per Ton.	Train-Miles per Ton.	Cost per Engine-Mile.	Cost per Train-Mile.
PASSENGER SERVICE.							
						Pence.	Pence.
July	4,924	4,652	77·5	63	60	6·5	7·0
August	4,713	4,565	85·6	55	53	6·2	6·3
September	3,976	3,776	75·9	52	49	6·5	6·9
October	3,168	3,149	66·6	47	47	7·2	7·2
November	6,740	6,566	126·9	53	52	6·4	6·6
December	3,216	3,216	60·2	53	53	6·3	6·3
FREIGHT SERVICE.							
July	2,161	1,953	95·9	22	20	18·6	20·6
August	4,128	3,505	172·0	24	20	14·2	18·1
September	7,447	6,133	310·0	24	19	14·2	16·9
October	7,401	6,689	317·7	23	21	14·6	16·1
November	5,372	4,926	167·0	32	29	10·6	11·6
December	986	986	34·5	28	28	12·1	12·1
Totals and Average Mileage, Consumption, and Cost.							
PASSENGER.							
—	26,737	25,924	49·27	54·3	52·6	6·5	6·7
FREIGHT.							
—	27,495	24,192	109·71	25·0	22·0	13·8	15·7

(For NOTES, *see* opposite page.)

TABLE 9 (*concluded from page* 281).

Comparative Statement of Performance of Locomotives.

For six months ending 31st December 1904.

WOOD.

Month.	Engine-Miles.	Train-Miles.	Total Tarrea.	Engine-Miles per Tarrea.	Train-Miles per Tarrea.	Cost per Engine-Mile.	Cost per Train-Mile.
PASSENGER SERVICE.							
						Pence.	Pence.
July	3,876	3,426	403·05	9·6	8·4	7·9	9·0
August	4,303	3,614	446·0	9·6	8·1	7·9	9·4
September	4,444	4,017	341·5	13·0	11·7	5·9	6·5
October	3,925	3,861	285·0	13·7	13·5	5·6	5·6
November	468	468	50·0	9·3	9·3	8·2	8·2
December	2,407	2,407	174·0	13·8	13·8	5·5	5·5
FREIGHT SERVICE.							
July	539	451	55·0	9·8	8·2	7·8	9·3
August	675	505	65·0	10·3	7·7	7·4	9·9
September	2,143	1,946	340·0	6·3	5·7	12·2	13·4
October	1,378	1,339	253·5	5·4	5·2	14·2	14·7
November	1,634	1,565	258·5	6·3	6·0	14·4	12·7
December	3,758	3,758	548·0	6·8	6·8	11·3	11·3
Totals and Average Mileage, Consumption, and Cost.							
PASSENGER.							
—	19,423	17,793	1,700·0	11·4	10·4	6·7	7·4
FREIGHT.							
—	10,097	9,564	1,520·0	6·6	6·3	11·6	12·1

NOTES.

1. From July to October for passenger engines, and from July to November for freight engines, an arbitrary allowance of additional mileage was made to cover "running light," "standing under steam," and "standing banked." This allowance was discontinued in November and December for passenger trains and in December for freight trains.

2. This statement does not include all engines in service, but several oil-burners, coal-burners, and wood-burners, which ran regularly in passenger and freight service were selected for the purpose of most accurate comparison.

3. Fuel oil was charged at \$2·52 (4*s*. 2*d*.) per barrel each month; coal at \$21·00 (£1 15*s*. 6*d*.) in July, and \$17·00 (£1 8*s*. 2*d*.) per ton in succeeding months; and wood at \$3·83 (6*s*. 5*d*.) per tarrea.

foreign countries, inasmuch as the same heat-producing power weighs less in oil than in coal, and the transportation and handling of oil are less costly than those of coal; consequently the freight, which is always an important element in the cost of fuel, would be in favour of oil.

It would appear from present indications that the price of oil in the United States will be governed by the refiners, and also that there will be an ample supply for many years of oil fuel for export to compete with coal. The indications also are that the oil regions are likely to extend in the States, as new oil-fields are being continually opened up, and oil is also being discovered in Mexico. If oil fuel is adopted as fuel in countries within easy reach of the United States, the author does not think the price of oil will be increased above what will enable the oil-producers to compete successfully with coal.

The object of this Paper is not to establish any scientific results, but it is, as will be seen, more of a history of a pioneer enterprise in Mexico which has attracted considerable attention amongst railway officials. The information is herein compiled in the hope that it may be of service to others who contemplate adopting oil fuel in the operation of their railroads, as the author thoroughly appreciated any information with which he was favoured at the beginning of this enterprise, especially by the International and Great Northern Southern Pacific and Santa Fé railroad systems of the United States.

The Paper* is illustrated by Plates 35 to 38.

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* Since the Tables in the Paper were compiled, the value of the Mexican silver dollar has increased from 1s. 8d. to 2s. (March 1906).

Discussion.

Mr. George E. Jones said he had had opportunities of making experiments with petroleum oil as fuel in locomotives abroad on two different occasions; first in 1885 when some oil wells were sunk in Beluchistan. Ordinary wood and coal-burning locomotives, altered somewhat in the way described by Mr. Urquhart,* were used. The trials were made on a level piece of road on the North-Western Railway in Scinde, and each description of fuel was used separately, in ordinary work. The comparative value of the fuel was found to be 1 lb. of oil equal to 1·42 lbs. of export English coal. The same description of oil was subsequently used in stationary boilers for some years, with very nearly the same result, 1 lb. of oil being found equal to 1·46 lbs. of local coal of good quality, equal to average English coal. It was observed that the number of gallons to do the work of 1 ton of coal varied considerably, due to the oil containing a quantity of water mixed with it at times, which could not be separated mechanically. He would be glad to know if that fact had been observed by the author, and if so, how dealt with.

Secondly, in 1899 he made some experiments with Borneo oil, supplied by the Shell Transport Co., with heavier engines than those used in the first trial, but fitted in the same way, on the same piece of road and using the different fuels separately, and 1 lb. of that oil was found to be equal to 1·4 lbs. of export English coal.

Mr. Lawford H. Fry said that to supplement the Paper he had placed on the table some blue prints showing two systems of oil-burning, which were largely used on locomotives in the Western and South-Western States of America. Fig. 5 (page 286) showed the standard system of the Baldwin Locomotive Works, while Fig. 6 (page 286) showed the arrangement used by the Southern Pacific Railway.

* Proceedings 1884, page 272.

(Mr. Lawford H. Fry.)

Fig. 5.—*Fire-box of Oil Fuel Locomotive* (Baldwin).

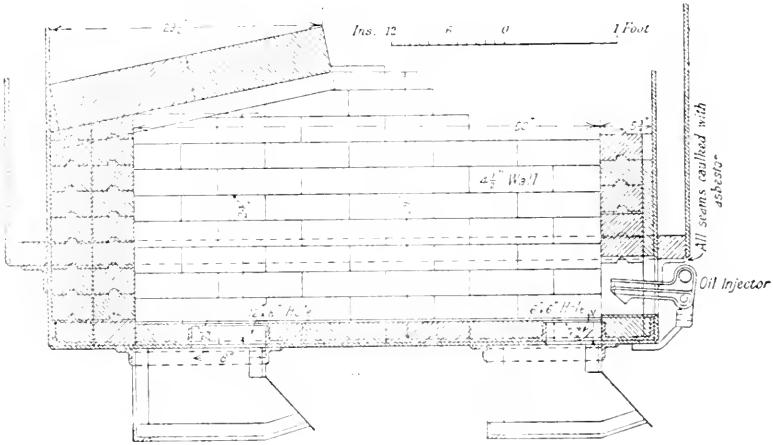
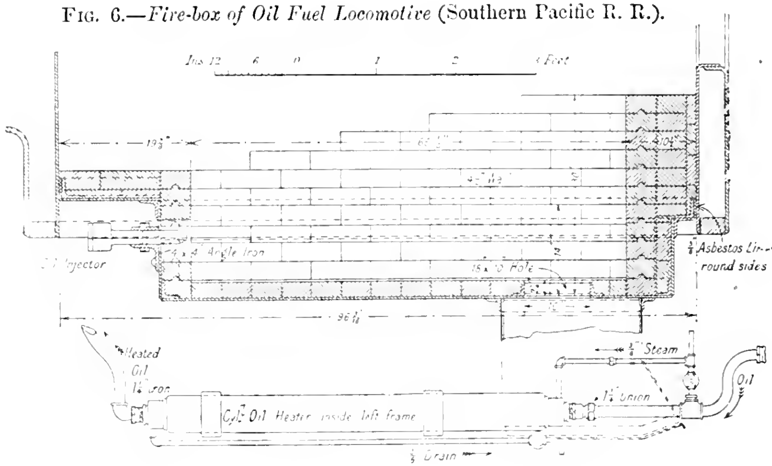


Fig. 6.—*Fire-box of Oil Fuel Locomotive* (Southern Pacific R. R.).



The Baldwin arrangement, Fig. 5 (page 286), was shown fitted to a small "Mogul" engine, with a fire-box 50 inches long by 25 inches wide inside the brickwork. The ash-pan, or what would be the ash-pan in a coal-burning locomotive, was lined to a height of about 29 inches with a 4½-inch brick wall, except at the tube sheet towards which the burner was directed. The tube sheet had a 9-inch fire-brick wall surmounted by a brick arch. The ash-pan had a layer of 2¾-inch fire-bricks and two openings for air, one 12 inches by 8 inches at the front and the other 6 inches square just below the burner, which was placed below the mud-ring at the back of the fire-box. This burner was of extremely simple construction, consisting of two chambers one above the other, the oil coming through the upper chamber and the steam through the lower. The chambers terminated in two wide horizontal slots. Through the upper slot the oil flowed in a film, which was turned to spray by the blast of steam through the lower slot. The Baldwin Locomotive Works' rule was to make the slot 1 inch wide for each 100 square inches of cylinder area.

In the Southern Pacific Railway arrangement, Fig. 6 (page 286), the burner was placed in the front of the fire-box and the spray was directed backwards. A sort of fire-brick wall was made, extending below the fire-box proper, with walls 4½ inches thick, except at the back towards which the oil-jet was directed. The back wall was 10½ inches thick. With that arrangement no brick arch was used, as the natural sweep of the gases from the front of the box to the back, and then forward again into the flues, filled the fire-box with the flame and protected the tube ends. In a fire-box 85½ inches long by 30 inches wide inside the fire-brick, air was supplied through an opening 18 inches by 10 inches near the back of the box. The Southern Pacific Railway passed the pipe supplying oil to the burner through a steam-jacket to cause it to flow more freely. In the Baldwin Locomotive Works' burner a certain amount of preheating was secured by the oil traversing the length of the burner in proximity to the steam.

He was rather surprised at the comparatively small economies which were shown by the figures in the Paper. Experiments in

(Mr. Lawford H. Fry.)

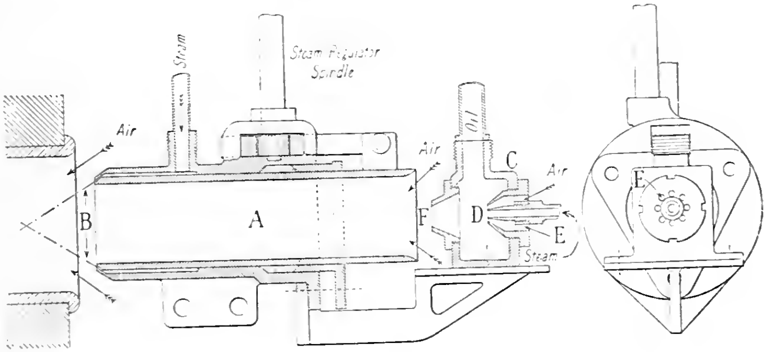
America had shown that the evaporative power of 1 lb. of oil was approximately $1\frac{3}{4}$ times that of 1 lb. of coal, and that figure was practically the same as that given by Mr. Urquhart as the result of his Russian tests.* Taking into account all the economies obtainable with oil, it was generally considered in America that 1 lb. of oil was equal to 2 lbs. of coal. The author showed (page 277) that 1 lb. of oil was equal to 1·33 lbs. of coal in freight service and to 1·21 lbs. of coal in passenger service. It would be interesting if some light could be thrown on the reason for that difference in value. At present he did not quite see the cause of it, unless the coal were more efficiently burned in passenger than in freight service, while the efficiency of the oil was the same in both. It had been his experience that the oil gave about the same efficiency, independent of the rate at which it was burned, while the efficiency of coal was of course largely dependent upon the rate of combustion.

Mr. HERBERT W. GARRATT said that, after listening to the interesting Paper which had been just read, he felt he could say but little on the question, but he happened to have had some experience of oil-burning on the Lima Railways, and he had made as simple and straighforward a burner as he could to control the air-supply with the greatest care; this had a great deal to do with the breaking up of the oil, and he thought sufficient attention was not given to it in many burners. The diagram of the burner was shown in Fig. 7 (page 289). The burner was a very simple arrangement, with which he had obtained fairly satisfactory results. With the object of being able to burn coal if the supply of oil gave out, a hole in the fire-box, similar to that in Mr. Holden's arrangement, was used as shown. A was a sliding sleeve, and the annular jet of steam at B was controlled by moving this in or out by any appropriate means. The oil was fed into the small casting C (where, as could be seen, it could not possibly choke), falling on to the combined steam and air-jet at D, this being the first breaking up of the oil, the air entering through the ring of inlet holes EE. At F was the

* Proceedings 1884, page 274; and 1889, page 48.

second mixture of air with the oil, and at B the third. Using that arrangement he got what he might call perfect combustion, and the cost of working came out as follows. The coal cost 35*s.* a ton, and the oil 45*s.* a ton, and for the same class of work the costs were for coal 25·48 cents (Peruvian money) as against 15·9 for oil, showing an economy of about 40 per cent. The oil burned came from the Negritos Wells of the London and Pacific Petroleum Co., and by the courtesy of Mr. Campbell Hunter he was able to give the analysis of the oil as follows: carbon 83·16 per cent., hydrogen 12·74 per cent., sulphur 0·015 per cent., and the specific gravity at 60° F. was 0·845.

Fig. 7.—*Oil-Burner used in Peru* (Garratt).



In reply to a question by Mr. Fry, he said that the hole in the fire-box was not placed at the side but through the back plates, pointing forwards towards the chimney, about 14 inches above the fire-bars, as in Mr. Holden's system, but there would be no objection to placing the burners beneath the foundation ring.

The fire-boxes were fitted in the usual way with suitable brick arches and walls. He could not say very much about the question of fire-box repairs, because the use of oil had not lasted long enough, but he thought they would be a little heavier than if the engines were burning coal. At the same time the engines on which the burners were in use were not suitable for burning petroleum, as

(Mr. Herbert W. Garratt.)
they had very short fire-boxes. With this burner, when burning a very small quantity of oil, as when running down long grades, there was an absence of the continual small explosions usual with the "box burners" (which it might be said only "steam shovel" the oil into the fire-box), owing to the feed being constant; and the steam and air could be so controlled that the combustion was constant however small the amount being burned, and no back-firing occurred in any circumstances.

Mr. C. HUMPHREY WINGFIELD said that, although he was not now connected with Messrs. J. I. Thornycroft and Co., he had the pleasure whilst he was there of making some experiments with a water-tube boiler using oil fuel, to which he had already referred in the Proceedings.* The author gave in Table 8 (page 275) the coal consumed per mile as greater than the equivalent oil-consumption by about 21 per cent. in the case of passenger locomotives and 31 per cent. in the case of goods locomotives. The difference between the two classes was doubtless partly due, as pointed out in the Paper, to the fact that the goods locomotives were waiting about with steam up for a much longer time than the passenger locomotives were, but he did not think that was sufficient to account for it all. He thought the goods locomotives must for some reason have been less economical than the passenger locomotives. A still better result could perhaps be obtained with oil than the Paper indicated, as, in his own experiments with Russian petroleum refuse oil, he found that he had to burn 66 per cent. greater weight of best Welsh coal than of oil in order to get a given evaporation, whereas, with presumably poorer coal, the author's figures, as just stated, showed the oil performance could be balanced by from 21 to 33 per cent. more coal. In confirmation of the speaker's results, it was interesting to note that Mr. Urquhart found he had to burn from 97 per cent. to 100 per cent. greater weight of coal than its equivalent of oil, this being with poorer coal than he (Mr. Wingfield) used. He gathered from Table 8 that the coal per engine-mile was 2·17 times as much for

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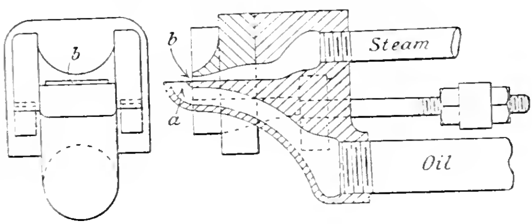
* Proceedings 1902, Part 3, page 434.

goods locomotives as for passenger engines, while the equivalent quantity of oil was only 1·97 times greater for goods engines. Those figures suggested that an oil-fired locomotive could be worked over a given range of power with a smaller variation of efficiency than a coal-burning one, which, if true, was very important.

The author called attention (page 278) to the importance of good bricklaying, which, of course, was a vital necessity in oil burning. With ordinary forced-blast he had found the addition of a little salt to the water, with which the fire-clay used as mortar was mixed, caused the latter to vitrify slightly when the furnace was at work, thus welding the mass of brickwork together. He believed that plan had since become a standard practice in the Royal Navy.

Fig. 8.—*Liquid Fuel Burner* (Best).



If the author had been present he would have asked him for more information with regard to the burners he mentioned. He had stated that Mr. Best's burner had given the most satisfactory results, and the speaker mentioned that the "United States Naval Liquid Fuel Board," a Committee appointed to examine into the use of liquid fuel, reported in 1904 as follows: "It may be remarked that the output with this burner exceeded that of any other burner tried during the tests," which bore out what the author said. The shape of Mr. Best's burner was shown in Fig. 8. There was a sort of spoon at *a*, on a level with which, at *b*, was a slit through which the steam issued and blew across the oil as it welled up in the spoon. In the description of the burner which he had read, it was pointed out that the lip *a*,

(Mr. C. Humphrey Wingfield.)

being uppermost, was protected from the fire, and in consequence the trouble which some other burners gave from carbonised oil choking the orifices did not occur. The fire did not beat upon the lip *a*, and it did not get choked up.*

He was rather surprised to see that the author referred to the trouble of making joints, as if it were a novel experience. That trouble had been met with by everyone who had to do with petroleum oil, especially by builders of tank-steamers for oil; and those who had had experience in the matter knew that the quality of the plate-work on such steamers must approximate to that on a boiler. Some shipbuilding firms of good standing, but who had not had the necessary experience, gaily accepted orders at a low price for tank-steamers, and then had to buy their knowledge. Unfortunately shipowners also had to suffer in such cases, as the tanks on oil-ships were constantly leaking and in need of repair, unless built in the light of special and extended experience with this class of work.

Mr. HENRY LEA, Member of Council, said that Mr. Wingfield had remarked (page 290) that he did not think the difference between the passenger-engine duty and the goods-engine duty was sufficient to account for the difference which was attributed to it in the Paper. That reminded him of a point which dealt with the subject, although it did not belong to locomotive engines. He made a very careful test of the petrol-consumption of a motor-car. On a run of a hundred miles without stopping it gave the rather remarkable result of 39½ miles per gallon of petrol, the speed being kept within 20 miles an hour. When the same car was taken into town and used for shopping purposes, which it might be said roughly represented the use of a goods engine as compared with a passenger engine, he could not obtain anything like half the number of miles out of a gallon of petrol which could be obtained if the car were given a continuous run. The two cases seemed to him to be perfectly parallel. It was difficult to say where the loss was, but it

* "The Mechanical Engineer," vol. xv, 27 May 1905, page 726.

inevitably did take place. If long stops, and many of them, were made, nothing like the same efficiency could be obtained from an engine as when it made comparatively long continuous runs, such as a passenger engine made in comparison with a goods engine.

Mr. M. S. Abrahams said he did not come to the meeting to speak, but to learn, and he had learnt that there were a great many more users of liquid fuel than was generally supposed. He represented the Shell Transport and Trading Co., and was greatly interested both in liquid fuel and motor spirit. He had personally attended various competitive trials, and found the comparison given by the author was far too low. It would be interesting to know that, at Messrs. Thornycroft's, on a water-tube boiler of their own make, he obtained an evaporation of 16·5 lbs. of water per lb. of oil used, and on a land boiler of the Lancashire type they were constantly getting 15·5 lbs. of water per lb. of oil as against 7·4 to 8 lbs. of water per lb. of coal on the same boiler. On the torpedo-boat "Surly," on the first trials which were made by the Admiralty under Sir John Durston, an evaporation of 15·8 lbs. was obtained, but this was in conjunction with coal.

The Shell Transport and Trading Co. owned a number of both large and small steamers, only three of which were not adapted for the use of liquid fuel, and used coal as a steam-raising medium. The rest all ran on liquid fuel only. From his experience, the comparison of oil versus coal could with safety be taken as 1 lb. of oil equalling 1·75 lbs. of coal, coal having a calorific value of from 11,000 to 14,000 B.Th.U., and oil 19,000 to 20,000 B.Th.U. A great deal of the coal efficiency went up the stack in the form of smoke, and was lost by the opening and closing of the door, and by the admission of cold air into the furnace; with oil every unit was consumed and brought into action, and consequently far better results were obtained, and a safe comparison of 1 against 1·75 could be taken.

Mr. H. F. Donaldson, Member of Council, said that he was reminded of some investigations which he carried out several

(Mr. H. F. Donaldson.)
years ago with oil fuel. There was something extremely fascinating about the appearance of an oil fire, and by the courtesy of the Shell Transport Co. he once had the opportunity of making a short trip in one of their steamers down in the stokehole. Though now and again, just at starting, there was a back flare, the fascination of watching the fire was, he thought, much greater than with coal, so much so that he came ashore with the idea that it was the fuel of the future, and that the Government had better be in the front rank in investigating the subject, and, if necessary, using the fuel on a larger scale. Money moved the world, and money must decide whether or not oil fuel could be adopted in this country. In order to test the point, again by the courtesy of the Shell Transport Co., a tank was put up, fitted to either one or two stationary boilers, and measurements were taken of the oil and water, as compared with the coal and water, in adjoining boilers. He had mentioned that there was a back flare now and again to start with in the stokehole of the steamer, and unfortunately a strong back flare occurred in the boilers on shore, which extremely alarmed all the people making the trial, because it lifted the boiler more or less off its seat, although it did not explode. The point he wished to urge was that economy was the matter which must be taken into consideration.

Referring to the figures which were given in the Paper, the price of coal with which comparison was made appeared to be somewhere about 24*s.* or 24*s.* 6*d.* a ton, and the saving did not seem to him to be commensurate with coal at that price. In the trials which were carried out at Woolwich, the price of the coal was, if he recollected rightly, somewhere about 12*s.* or 15*s.* a ton in the bunkers, and they could not make oil pay at the price at which the Shell Transport Co. were then prepared to sell oil. That Company offered to give the Government the lowest terms, if they agreed to use the fuel, and the Government was willing enough to accept if those terms were such as would have compared with the price which they were paying for coal. Experiments were carried out, which extended over a considerable period, with the result that they ultimately had to come to the conclusion that, in the neighbourhood of London, with

the price of coal which was then ruling, and which practically ruled now, oil fuel could not be used economically compared with coal. He did not know whether the price of oil was coming down, but so far as he could see there was no prospect of the price being lowered in the near future to such an extent that it would compete with coal.

With regard to the question of brickwork, to which Mr. Wingfield had referred (page 291), and the duration of first-class materials and workmanship, he thought there had been a little begging of the question in the Paper, because the author said it might last a year even under the best circumstances. It would have been much better if he had said it did last a year, because if the best of everything were used, and there was then only a possibility of it lasting a twelvemonth, a very considerable expense would probably be incurred in upkeep and maintenance which would have to be added to the other charges.

Mr. S. F. Stackard desired to mention his experience—as a glass manufacturer—of the use of liquid fuel. It did not come under the heading of liquid fuel for locomotive purposes, but at the same time it might be interesting to some of the members to know that in London, at any rate, some manufacturers had been experimenting for a considerable time with liquid fuel for the melting of the particular material with which they dealt, as well as in some instances for metallurgical purposes generally. The objection which had been raised by one or two speakers had also been experienced by his firm—Messrs. J. A. Curle, of South Hackney, London—namely, that the liquid fuel was in the hands, to a certain extent, of, he might almost say, monopolists, and that as a rule when a demand for the article arose the tendency always had been for the price to be put up against the users. The consequence was that, however much the industry might have developed, the people who ought to endeavour to foster the use of this form of fuel had generally worked against it. In spite of those drawbacks, his firm was still persisting in the use of liquid fuel, with a fairly successful result.

One great advantage in the furnace used, especially so far as London was concerned, was a complete absence of smoke. His

(Mr. S. F. Stackard.)
firm had a burner of their own, which they thought was very satisfactory in that respect. The burner did not carbonise or clog, which was another very great advantage. So far as the steam generation was concerned, under a little multitubular vertical boiler, not lagged, which, as engineers knew better than he did, was pretty well the most extravagant form of boiler that could be used, the very satisfactory evaporation was obtained of 13 lbs. of water per lb. of oil. In a Lancashire boiler they would expect to get the evaporation which had been mentioned of 15 to 1 or more; but with a water-tube boiler, with a properly constructed fire-box, a still better result might be obtained. If any of the members were interested in the application of liquid fuel to metallurgical processes, he thought if they paid a visit to his firm's works they might at any rate learn something. As Mr. Donaldson had stated, there was something very fascinating, and also very costly, about experiments with liquid fuel. He knew that the Navy were experimenting very largely with it, and he was aware that in a great many instances the danger of back-firing had been experienced. Parenthetically he might state that he was present without a moustache very largely on that particular account. That accident happened when a steam burner was being used; but with the burner at present in use, with reasonable care, there was no fear of similar accidents.

He had experimented with a great many liquid-fuel burners, and his experience was that, so far as the spraying medium was concerned, there was certainly no comparison between compressed air and steam; and he believed, with all deference to the representative of the Shell Transport Co., it would eventually be found that, having regard to the question of distillation and condensation of feed-water, compressed air would, for marine purposes, be the future medium for spraying the oil into the furnace, not only because of the distillation of the water and of the steam required for spraying, but because of the very much better combustion that was obtained by compressed air as a spraying medium than by steam. His experience was that compressed air, in almost any form of burner, was 15 per cent. better as a spraying medium than steam. He believed that, in the Navy, experiments were being carried on with the fuel under heavy mechanical pressure without compressed air beyond the ordinary forced draught

at present in vogue. The Admiralty experts of course should know better than himself, but he was afraid that there might be trouble with this system on the score of this very danger of back-firing which, in the confined space such as that of a stoke-hold, would be fraught with serious consequences to the men. It might be argued that in driving the oil into the furnace the water was split into its gases, but he thought it was a well-known axiom of the application of liquid fuel that it took as much energy to split the water into its gases as those gases represented in heat energy when they were consumed. The subject was one in which he was particularly interested, and if any of the members present thought the question worth consideration of seeing how liquid fuel might be applied to furnaces for metallurgical purposes, he would be very pleased indeed to show them his works. One interesting experiment which he had conducted with the burner he used was that, for the purposes of intense heat, an auxiliary stream of compressed oxygen was conducted through the burner, and thereby a very great heat had been obtained. He had carbonised electric filaments in a crucible, and had been given to understand that he had produced the next most intense heat to that of the electric arc. He was told by the people who supplied the compressed oxygen that the burner would be melted, but as a matter of fact it survived the test very satisfactorily.

The President said that, for the information of any of the members who decided to avail themselves of the kind offer which Mr. Stackard had made, that gentleman was the representative of Messrs. J. A. Curle, glass-bottle manufacturers, Perseverance Glass Works, Victoria Park Road, South Hackney, London.

Mr. John F. Robinson, Member of Council, said that when looking at the drawings of oil-burning locomotives it had always struck him as a curious fact that the same form of fire-box was used as in a coal-burning locomotive. He thought there must be something wrong there. In the case of narrow-gauge engines, all kinds of abnormal shapes were resorted to in order to make up a fire-box which would give the requisite grate area and heating surface, but

(Mr. John F. Robinson.)

why the same particular form should be adopted in the case of an oil-burning locomotive he could not understand. He thought the whole subject required to be considered again from the point of view of first principles, and not from the practice which had been accumulated from coal-burning locomotives.

Mr. Campbell M. Hunter said that Mr. Stackard had referred to the use of compressed air for vaporising oil. He did not know whether that principle had yet been tried on any locomotives, and it certainly would be very interesting to see what efficiency could be obtained on them when using compressed air. He had been carrying out some experiments in the neighbourhood of London with compressed air, and the results obtained were certainly very encouraging. He had not been able to make any comparative experiments between steam and compressed air, as there were no means of raising steam at these Works. A small air-compressor was put in with the expectation of using about 5 lbs. per square inch to vaporise the oil; but he was much surprised to find that the best results were obtained with about $1\frac{3}{4}$ lbs. per square inch, which he fancied was about the lowest result on record. The furnaces in which the oil was sprayed had been constructed for the use of coke; and before any expense was undertaken in the way of making a complete conversion, it was suggested that the same old furnaces should be used, and that the fire-bars should be covered with broken crucible pots and firebrick. The result of six hours' working was that the whole of the firebrick ran into a solid mass, and the burners had to be shut down, as not enough air was entering to make the combustion perfect. When the furnaces had cooled down, it was found that the fire-box was one solid mass of vitrified firebrick, which showed that the heat was fairly satisfactory. The fire-box was then removed, and different arrangements made, with the result that the same output was obtained from 1 ton of oil which had previously been obtained from just a little less than 3 tons of coke. He did not quite know how that would compare with coal, but the calorific value of coke being roughly 14,000 B.Th.U., and as coal was about the same, it showed a very high efficiency between the oil and the

coke or coal. Since then the design of the furnace had been modified, so that now he was no longer able to make comparisons between the coke and the oil, but he felt confident that the new type of furnace was more suited for utilizing the heat, and not so much of this was lost up the chimney stack.

The President said that the report of the discussion would be sent to the author, in order that he might have an opportunity of replying to the questions asked and the criticisms made. He asked the members to accord a hearty vote of thanks to Mr. Greaven for his interesting Paper, which had produced such an admirable discussion.

The resolution was carried by acclamation.

Communications.

Mr. J. J. Kermode wrote that the data contained in the Paper were bound to be of interest to engineers and to all who were interested in the use of oil fuel, but as historical matter it was not calculated to show any advance in the economical use of liquid fuel, which should prove superior to coal pound for pound in actual working for locomotive firing in the ratio of 2 to 1, or nearly so. As long ago as 1891 he had information of oil fuel (residium) being used with perfect success on the Oroya, Molliendo, Arequipa, and Puno Railroads, in Peru. In 1890 careful experiments were made on the Oroya line to test the comparative efficiency of oil and coal in locomotives. Six months' careful experimenting decided that fuel oil was in every respect superior to coal. The average consumption of coal for the month was 79·3 lbs. per train-mile. The average consumption of fuel oil per train-mile was 38·55 lbs., or slightly less than 50 per cent. of the amount of coal used. On the Oroya line, on the 4 per cent. grades, as much as 220 lbs. of coal was burnt per mile for 120 lbs. of oil.

(Mr. J. J. Kermode.)

The engines used were American Rogers, "Mogul" type, with driving wheels 47 inches, cylinders 18 inches by 24 inches stroke. Total weight of engine 38 tons; tender 28 tons. Regular train, five cars; average weight of car, 18 tons gross. Total weight of train including tender 118 tons. Eight and ten cars were sometimes taken as far as Chosica, from where the 3 and 4 per cent. grades began.

TABLE 10.

Stations.	Distance from Callao.	Height above Sea-Level.	Average Grade.
	Miles.	Feet.	
Callao.	0	—	—
Lima	8½	448	1 in 100
Santa Clara . . .	18¼	1,312	1 in 60
Chosica	33½	2,832	1 in 53
San Bartoleme . .	47	4,919	1 in 34
Verrugas Bridge. .	51¾	5,840	1 in 27

With regard to the behaviour of the engine on all these heavy grades, the steam-gauge always recorded from 135 to 140 lbs., never falling below 135 lbs. As a rule the hand stood immovable at exactly 140 lbs., and although the safety-valve would blow off at 142 lbs., so admirably was the fire at all times under control that it very rarely blew off. On all the grades up to 3 per cent. no smoke whatever showed from the funnel. On the 4 per cent. grades a slight hazy smoke would show at times.

In a Paper,* in 1897, by Mr. John A. F. Aspinall, it was stated in connection with the performance of one of the Great Eastern Railway locomotives that when coal was used as fuel the locomotive consumed 35·40 lbs. per mile, but if oil were used, the consumption was 16·5 lbs. per mile, the oil fuel used being Russian Astatki.

* Engineering Conferer ce, 1897. Proceedings, Institution of Civil Engineers, vol. cxxx, page 196.

The theoretical value of petroleum from and at 212° F. was given in Table 11 :—

TABLE 11.

Fuel.	Lbs. of Water per Lb. of Fuel.
Pennsylvanian heavy crude oil	21·48
Caucasian light crude oil	22·79
Caucasian heavy crude oil	20·85
Petroleum refuse	20·53
Good English coal	14·61

The Paper further stated that a liquid-fuel system did not necessitate the radical alteration of a boiler, as in most cases arrangements could be made: first, either to burn coal alone; secondly, coal and oil in such proportions as might be convenient; and thirdly, oil alone. The use of liquid fuel was referred to as an ideal method of raising steam.

In 1889 * important data appeared in connection with the relative consumption of coal and oil on the locomotives of the Grazi and Tsaritzin Railway, Russia. Referring to the Tables given, the consumption of coal and of petroleum per engine-mile in six-wheeled coupled 36-ton goods locomotives was as follows:—Coal 55·65 lbs., petroleum 30·72 lbs. These figures represented the average for twelve months. For eight-wheeled coupled 48-ton goods locomotives the consumption was stated as follows:—Coal 79·08 lbs., petroleum 40·47 lbs.

The foregoing particulars were matters of history, but they abundantly testified that the best possible method of burning liquid fuel did not obtain on the Tehuantepec National Railroad, Mexico, and Mr. Greaven's Paper was the most conclusive proof that much

* "Engineering," 8 February 1889, page 132.

(Mr. J. J. Kermode.)

remained to be done in improving the equipment of the locomotives to ensure further economy. The results obtained were disappointing, and certainly would not satisfy the writer in connection with a boiler of the most ordinary kind. The consumption of oil as compared with the consumption of coal in Table 8 (page 275) compared very unfavourably with the figures quoted by the writer. In Papers dealing with oil-fuel steam tests, or in reference to process furnace tests, the calorific value of the oil in British Thermal Units, the chemical analysis, the flash point, and specific gravity of the oil used were generally forgotten, with the result that every one, except those responsible for the tests, was in utter ignorance of their value. He might go further and say that too often tests were carried out with oil fuel of which nothing was known to those conducting the tests, save that it was oil fuel. In the present instance, one had to assume a value for the Beaumont oil fuel used on the Tehuantepec Railroad, and if this were placed at an average of 19,000 B.Th.U. per lb., one would expect to exceed the results obtained with coal by at least 65 per cent. with a steam-jet burner of good design and from 75 to 83 per cent. with a hot-air-jet burner of good design. These figures, however, related to boilers other than locomotive engine-boilers, and with these latter, the condition under which they worked, operated against strict economy in coal consumption, whilst the same conditions did not affect the use of oil fuel. It was for this reason that the comparative performances with coal and oil fuel instanced by the writer as referring to other boilers, fitted either with steam-jet burners or with hot-air-jet burners, would not apply to the locomotive engine-boilers, and with these latter the superiority of the performance with oil fuel as against coal would be more pronounced.

The superiority of air over steam for jetting had often been the subject of controversy, and even now champions were not wanting for the steam-burners; however, he had operated nearly every kind of device for burning liquid fuel, and his experience was that he never operated anything which was so efficient as the hot-air burner. The space taken up by an air-compressor and its cost were regarded by many as sufficient objections to the use of air for jetting, but

when it was more generally understood that a saving of from 15 to 30 per cent. of fuel was effected by the adoption of the hot-air system for steam-raising purposes as compared with results obtained with steam-burners, it would be readily admitted that the extra cost for an air-compressing engine was more than justified. This was signally demonstrated in process-working furnaces, and last week his firm received a report on tests made with their hot-air burners which were at present in competition with steam-burners in a works near London, and the saving of fuel through using the hot-air burners amounted to 46 per cent. With their steam-burner employed for locomotive work, they reckoned 1 lb. of oil fuel of a calorific value of 19,260 B.Th.U. nearly equivalent to 2 lbs. of coal.

Some prominence had been given in the Paper to the importance of the brickwork which was necessary in locomotive furnaces, but he thought it had been frequently shown that brickwork, be it ever so well designed and built, would not altogether remedy defective jetting and defective design of the jetting instrument itself. Unless it were specially specified that a boiler was to be fired exclusively with liquid fuel, his firm took no special heed of the brickwork, but simply covered the fire-bars with broken firebrick. During their trials on H.M. Torpedo-Boat Destroyer "Surly" in 1902, they were obliged by the conditions laid down by the Admiralty to obtain full power without bricking up the furnace or disturbing the fire-bars, and they demonstrated for the first time that it was possible not only to obtain full power on a torpedo-boat destroyer with liquid fuel, but that it could be accomplished without altering the furnace as arranged for coal.

During the discussion he noted that one of the speakers referred to evaporation performances per pound of oil fuel burned, without stating definitely the circumstances under which the tests were taken. No mention was made of boiler pressure and temperature of feed-water; it was not stated whether the evaporations named were those at boiler-working pressure from feed at a certain temperature, or whether they were from and at 212° F. Broad statements of this character were misleading. Similar statements were frequently

(Mr. J. J. Kermode.)
made with regard to oil fuel, of which there were many and various kinds, differing in chemical composition, and all more or less differing in calorific value. Until it was recognised that there was as much difference in the character and quality of liquid fuels as there were differences in the character and quality of coal, and until the full data necessary to make a strict comparison of results were forthcoming, discussion was bound to be of a conflicting nature. Mr. Wingfield referred (page 291) to the tests conducted by the United States Naval Liquid Fuel Board in 1904. These results the writer had compared with the results obtained by his firm at Portsmouth in 1902 for the British Admiralty, and he was glad to say that the British tests were relatively more successful than any performance mentioned in the report of the United States Naval Liquid Fuel Board.

Mr. C. W. KINDER, C.M.G., General Manager and Engineer-in-Chief of the Imperial Railways of North China, in answer to an invitation to take part in the discussion, wrote that he was interested in the use of oil fuel, as four of their recent engines were being fitted with the system, but so far he had had no experience in that direction.

Rear-Admiral GEORGE W. MELVILLE, late of the United States Navy, wrote sending a fully illustrative report, dated 1904, of the apparatus used in, and the results obtained from, tests on the relative evaporative efficiencies of coal and liquid fuel under forced and natural draught, made by the Navy Bureau of Steam-Engineering at Washington.

Mr. EDWIN L. ORDE wrote that a comparison was given (page 275) between the consumption of oil fuel and coal, but the figures given only showed a saving of some 17 per cent. in favour of oil. This was considerably less than the saving which had been effected in steamers in which liquid fuel had been used, and was also considerably less than the saving which he found could be made under a water-tube boiler which was fitted up for experimental purposes, where 25 to 30 per cent. appeared to be a fair average.

As the conditions which obtained in a locomotive fire-box were in every way satisfactory for the use of liquid fuel, it seemed curious that a higher duty had not been obtained from it, and he ventured to suggest that the cause might perhaps be found in the amount of brickwork which had been placed in the fire-box, which, of course, tended to increase the temperature of the waste gases, and consequently lowered the evaporative duty of the fuel. He was glad to find that the author's experience of the effect of the small percentage of sulphur which occurred in oil fuel of this quality exactly coincided with his own.

Mr. John D. Smelt, formerly consulting engineer to the Argentine Great Western Railway, wrote that liquid fuel was tried on about a dozen engines of that company, but unfortunately the system had to be abandoned before any very reliable or useful statistics could be tabulated, owing to the supply of petroleum in the neighbourhood of Mendoza suddenly failing. At the time the trials were made (in 1891–92, at which latter date the supplies of petroleum ceased) well-determined data on the comparative heating power of coal and petroleum were not obtained, but theoretically it was known that $1\frac{1}{2}$ lbs. of the best Welsh coal was equivalent to 1 lb. of petroleum; the two fuels could not, however, be compared satisfactorily. The cost of petroleum was taken at $12 gold per metrical ton, excluding expenses of handling, etc., which would probably increase the cost to $13. The cost of coal at Mendoza, at the time the trial was made, was $16·0004 gold per metrical ton, placed on the tender. The present cost of coal at Mendoza is about $13 gold per metrical ton, placed on the tender, and there is no doubt the price of petroleum would be regulated according to the price of coal ruling at the time.

Mr. Greaven wrote, that he had read with much pleasure the discussion on his Paper, and it was a source of satisfaction to him to observe that the subject treated was one of interest and that it had elicited so much valuable information from those who had had more experience in the burning of oil fuel than he himself had.

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With regard to the comparative consumption of coal and oil, this greatly depended on the service in which the fuel was used, and on the quality of the fuels employed. He noticed that in the experiments made by Mr. George E. Jones (page 285) the following ratios were found to exist under varying conditions:

1 lb. oil equals	1·42 lbs.	English	export	coal.
1 ,, ,, ,,	1·46 ,,	,,	,,	,,
1 ,, ,, ,,	1·40 ,,	,,	,,	,,
1 ,, ,, ,,	1·31 ,,	,,	,,	,,

The American experience referred to by Mr. Fry (page 288) and also Mr. Abraham's experience (page 293) showed that

1 lb. oil equals 1·75 lbs. coal.

Dr. Charles B. Dudley, in his lecture before the Franklin Institute, Pennsylvania, in 1888, gave the following comparisons:—

Theoretical anthracite . .	1 lb. oil equals	1·61 lbs.	coal.
,, bituminous . .	1 ,, ,, ,,	1·37 ,,	,,
Urquhart's experiments . .	1 ,, ,, ,,	1·756 ,,	,,
Peninsular Car Co. . . .	1 ,, ,, ,,	1·742 ,,	,,
Elevated Railroad, New York .	1 ,, ,, ,,	1·785 ,,	,,

Mr. G. R. Henderson, in his valuable work "Locomotive Operation," published in Chicago, stated that "The heat-producing power of fuel oil is generally stated at from 1·4 to 1·8 that of coal, or that 1·4 or 1·8 lbs. of coal are required to generate the same amount of steam as is produced by 1 lb. of oil, but there are many kinds of coal, and this is rather indefinite." As there are many kinds of coal so there are also many kinds of oil. Dr. Dudley mentioned in his lecture already referred to, and speaking of Russian oils, that "they have a fire test of about 320° to 340° F. and look, and, in fact, are very much like our ordinary reduced petroleum, known in the market as 'well oil' and used for lubrication." In another part of the lecture he stated, "the oil which is now used on the Grazi-Tsaritzin Railway and which is believed to be safe to use, is an oil not below 300° F. fire test."

The report on the U.S. Naval Liquid-Fuel tests, conducted by direction of Rear-Admiral George W. Melville of the U.S. Navy, and published at Washington in 1904, contained the following:—"The

character of the oil used during official tests can be best appreciated by comparing it with the average grade of the crude product. The changes wrought by the refining process can thus be clearly seen by comparing the analyses of the crude Beaumont product and that used in the experiments :—

Analysis of Beaumont Crude Oil.

Carbon (C)	84·60 per cent.
Hydrogen (H)	10·90 "
Sulphur (S)	1·63 "
Oxygen (O)	2·87 "
Calorific value per lb.	19,060 B.Th.U.
Specific gravity	0·924
Flash point	180° F.
Fire point	200° F.

Analysis of Oil used in Tests.

Carbon (C)	83·26 per cent.
Hydrogen (H)	12·41 "
Sulphur (S)	0·50 "
Oxygen (O)	3·83 "
Specific gravity at 60° F.	0·926
Flash point	216° F.
Fire point	240° F.
Vaporisation point	142° F.
Calorific value	19,481 B.Th.U.

These analyses show the improvement of the oil on distillation and that nearly all the sulphur was removed."

In comparing results obtained it was therefore very necessary to know the exact conditions under which the tests were made. This would appear to be particularly necessary in comparing results obtained from Beaumont with those obtained from Russian oil. Most of the satisfactory comparative results referred to in the discussion as having been obtained with oil fuel were arrived at on trial or test trips, when it was usual to have everything in first-class order, arranged to give the most economical results, and superintended by an official; whereas the results set forth in the Paper were those of several months' routine work in ordinary railroad service and under certain difficulties in operation, inasmuch as the road was still under reconstruction, and irregular train running was unavoidable.

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The author had made several trial test trips, personally conducted, during which $3\frac{1}{2}$ barrels of oil (1,102 lbs.) were found to equal 2,240 lbs. of coal, and he had no doubt that the efficiency could be improved above that set forth in the Paper when the general working of the road was in a normal condition, that is when the reconstruction was finished, and all trains were run regularly to time. In compiling data for the Paper he acted on the assumption that the Members, especially those connected with railways, would be interested in the practical results obtained in actual service extended over several months, even under adverse conditions. Liquid fuel was new to the enginemen, and, as mentioned, the road was still partly in reconstruction, causing irregular working, with consequently less economical results than could be obtained in operating a road free from these drawbacks. The class of coal used and with which the comparisons were made was good Virginian (frequently Pocahontos) and Cardiff steam coal; the oil was therefore tested against practically the best steaming coal to be procured.

With regard to the difference in consumption of oil between freight and passenger trains, the cause of this difference would be apparent from the following explanation. The passenger trains made an uninterrupted quick run, as far as the reconstruction of the road would allow, and the engines were credited with mileage for practically every lb. of coal consumed, whereas the freight engines were delayed at stations for crossings, shunting, and in consequence of the reconstruction of track, bridges, &c., and these delays were often considerable. Goods engines, which burnt coal and were frequently delayed, consumed a certain quantity of coal during the delays, while oil-burning engines under the same conditions did not consume any oil while standing, because the oil supply was cut off. It might further be added that, after some experience, it was found that the burner orifices used on the passenger engines were wider than was necessary, and they were replaced by smaller burners. This had only been done on one engine when the Paper was written, and the subsequent consumption of oil by this passenger engine was found to be considerably less, the ratio of economy over coal more

closely approximating that of the goods engines. Members who had had experience in controlling or testing fuel consumption on railways would be fully able to appreciate Mr. Henry Lea's remarks (page 292), that with long and numerous stops it was not possible to get the same efficiency from an engine as in the case of continuous running.

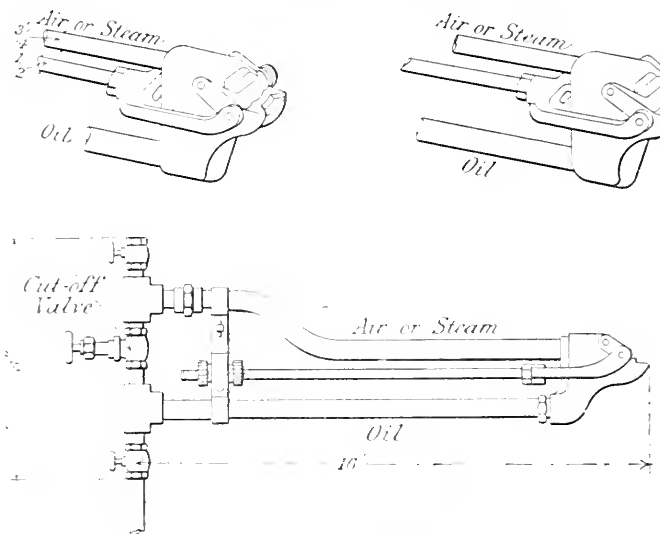
With reference to Mr. H. F. Donaldson's remarks (page 295) about the fire-brick work, this was an expense to be reckoned with and was unavoidable. Brick-work in a locomotive fire-box which would last a year without renewal must be considered as highly satisfactory. With regard to Mr. Wingfield's observations (page 291) on fire-boxes, a copper fire-box lent itself better than a steel fire-box to the more sudden changes of temperature experienced while burning oil fuel and was less liable to fracture.

The "Best" burner was manufactured by the International Calorific Co., of Los Angeles, California, and New York, and differed from other flat-spray burners in that the oil was supplied through the bottom chamber and the steam through the top; with the Baldwin burner, described by Mr. Fry (page 287), the reverse conditions prevailed. It was claimed for the "Best" burner that the supply of oil through the bottom chamber obviated the clogging of the steam orifice which, when the oil was supplied from above, was liable to take place by the oil finding its way into the lower or steam orifice when the steam was shut off. Fig. 9 (page 310) showed this burner more fully than the illustration in Fig. 8 (page 291). It would be seen that, by an ingenious arrangement, the orifices could be opened by means of a bridle, which facilitated cleaning without removing the burner from the engine.

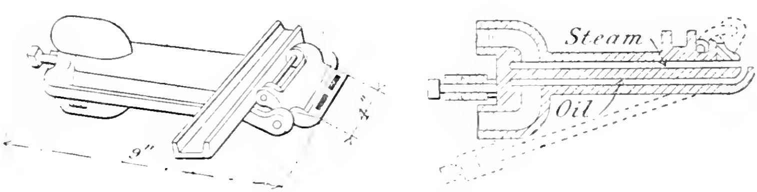
With regard to the use of air-pressure for spraying the oil from the burner, this system could of course only be adopted on a locomotive fitted with a small air-compressor or an air-pump. The author had made trials with air-pressure on a locomotive provided with an air-pump (Westinghouse), and while the result was highly satisfactory as regards combustion, the demand on the air-reservoir was such as to make it necessary to work the air-pump at an excessive speed, and furthermore it decreased the efficiency of the

(Mr. Greaven.)
air-brake; also, the additional consumption of steam necessary to keep up the air-pressure was greater than that which would be required for spraying the oil with steam direct. A subsequent test was made on the stationary boilers referred to (page 276), and a more

Fig. 9.
"Best" Burner as used on the National Railway of Tehuantepec.
For Stationary Boilers.



For Locomotive Boilers.



satisfactory result was obtained, but the air-pressure was taken from an air-compressor.

With regard to the presence of water in the oil fuel, referred to by Mr. Jones (page 285), the author had some trouble in this respect, and on making investigations in Texas he found that this difficulty

could be eliminated to a considerable extent by drawing the oil supply from a point in the oil tanks somewhat above the floor of same. The water was gradually precipitated to the bottom of the tanks, and an outlet valve or cock was provided at the extreme bottom of the tank through which water was drawn off occasionally; there would still be a certain quantity of water in the oil, but, if the above operation was observed at the storage tanks as well as at the auxiliary tanks, the water would usually be reduced to such an extent that its presence would not materially interfere with the burning of the oil.

It was not the object of the author to treat of the application of oil fuel to various industries, but, as this branch of the subject had been brought up in the discussion, it might be of interest to mention a few of the many uses to which oil as fuel was being applied in the United States and elsewhere. A most interesting application was in connection with iron and steel tube-welding for locomotives; many suitable furnaces were constructed for this purpose, and the output of one furnace with a mechanical tube-welder was as high as 340 tubes scarfed and welded in six hours by one man and a helper, the scarf and weld being absolutely free from scale and quite clean. Oil fuel was wonderfully well adapted for rivet and bolt-making furnaces and machines. Visitors to the Pullman Works, near Chicago, would have observed the large number of forging machines which were supplied from oil furnaces. Oil fuel was most suitable, and was extensively used for tempering and spring-setting furnaces, annealing furnaces, scrap-iron furnaces and cast-iron foundry furnaces, and an interesting application was seen by the author in a weed-burning apparatus used for travelling over the road bed on the Southern Pacific Railway.

Regarding the superheating of the oil, many arrangements existed; sometimes a coil of piping for steam was introduced into the oil tank, and almost all oil burners were so constructed that the steam passed through a superheating chamber before reaching the burner. As the oil also passed through a separate chamber of the same heater, the necessary heating of the oil took place. The author found that superheating on the Tehuantepec Railway was quite unnecessary.

(Mr. Greaven.)

With reference to Mr. J. J. Kermode's remarks (page 303), in regard to taking no special heed of the brick-work and burning oil fuel in a boiler without altering the furnace as arranged for coal, the author had no doubt that if the flame from an oil burner were brought in direct contact with the plates and tubes of a locomotive, steam would be generated very fast with an economical consumption of fuel so long as the fire-box would stand it, but the expense of renewing fire-boxes and tubes would more than counterbalance the additional efficiency obtained from the oil.

FRANKLIN BI-CENTENARY,

17th to 20th April 1906, in Philadelphia.

The American Philosophical Society having invited this Institution to send representatives to the celebration, in Philadelphia, of the Two-Hundredth Anniversary of the Birth of Benjamin Franklin, the Council accordingly appointed the following three Members to represent the Institution:—Dr. Coleman Sellers, of Philadelphia, Mr. Robert W. Hunt, of Chicago, and Mr. Ambrose Swasey, of Cleveland, Ohio. Their report is as follows:—

Report.

Philadelphia, Pa.,
30 April 1906.

Mr. Edgar Worthington, Secretary,
The Institution Mechanical Engineers,
Storey's Gate, St. James's Park, Westminster, S.W.,
London, England.

Dear Sir,

The delegates duly appointed by your Council to represent the Institution of Mechanical Engineers on the occasion of the Bi-Centenary of the Birth of Benjamin Franklin have the honour to submit the following report of the proceedings.

The occasion was made notable by the gathering together of prominent men of science from all parts of the world, and the popular interest in the event was evidenced by the general display of decorations throughout the principal business thoroughfares of the city and by appropriate illuminations, particularly at the City Hall, where long strings of electric lights reached to the dome of the tower 500 feet above the street and on the four principal façades of the building. The arrangement of the lights represented a kite and suspended key, commemorating Franklin's notable experiment whereby he demonstrated the identity of lightning and what was then known as statical electricity. Franklin's services as the first Postmaster-General of the United States were commemorated by a parade of Letter-Carriers, while his association with the first Masonic Lodge in America was made of public interest by a very complete loan exhibition of Franklin relics at the Masonic Temple.

The opening ceremonies of the celebration, under the auspices of the American Philosophical Society, occurred on the evening of April 17th, when two hundred delegates from various societies and institutions of learning throughout the world were presented to the officers and members of the Society at Witherspoon Hall. The delegates, on this occasion, presented their credentials, and those so prepared read addresses from their respective Societies. As your representatives had no instructions of this character, they, with others similarly situated, took a less prominent part in the ceremonies.

At the close of these opening exercises, Mr. Carnegie, Lord Rector of the University of St. Andrews, conferred the degree of LL.D. upon Miss Agnes Irwin, Dean of Radcliffe College and a great grand-daughter of Franklin, who had received in 1759 that degree from the same University.

On April 18th was held a general meeting of the Philosophical Society, when election of new members took place and papers were read upon various scientific subjects, all of which will be recorded in the proceedings of the Society and transmitted to the Institution in due course. On this occasion Sir George Howard Darwin presented to the American Philosophical Society a medallion of Franklin, which was received at the hands of the presiding officer, Professor N. B. Scott, of Princeton University, a great-grandson of Franklin, and with it also a medallion of Erasmus Darwin, a great-grandfather of Sir George. The evening session was presided over by Professor Edward L. Nichols, of Cornell University, who read a Paper entitled "Franklin's Researches in Electricity."

On April 19th the trustees, faculty, and students of the University of Pennsylvania, of which Franklin was a founder, held a meeting at the Academy of Music which was both interesting and impressive. The ceremonies included an address by Hampton L. Carson, Attorney-General of Pennsylvania, and the conferring of Honorary Degrees upon distinguished men, including the degree of Doctor of Laws upon His Majesty King Edward VII., *in absentia*, who was represented by his Ambassador, Sir Henry Mortimer Durand.

On the evening of the 19th a reception was tendered the delegates at the Bellevue-Stratford Hotel, which was attended by the Mayor, other City and State officials, Members of Congress, and prominent citizens.

On the 20th the visiting delegates and members of the American Philosophical Society met at the Academy of Music, where the ceremonies included the presentation by Mr. Root, Secretary of State, to the Republic of France, through its Ambassador, M. Jusserand, of the Franklin Medal, made of American gold, and struck in accordance with the Act of Congress in commemoration of the important services that France rendered through Franklin to the United Colonies during their struggle for independence. This significant incident was preceded by addresses by Dr. Horace Howard Furness, Mr. Choate, late Ambassador to England, and President Eliot of Harvard University. An interesting event on this occasion was the presentation by

Mr. Choate, on behalf of Earl Grey, Governor-General of Canada, of the portrait of Franklin that was taken from his residence by Major André during the British occupation of Philadelphia in 1778, and which has been retained since that time by the descendants of General Grey, to whom André presented it. The correspondence involved in this gracious act of restitution by Lord Grey was received with much enthusiasm.

On the afternoon of the 20th the visiting delegates and members of the American Philosophical Society met at the Hall of the Society, and proceeded in a body to Christ Church yard, where they were met with military escort, and the ceremony of placing wreaths on Franklin's grave was performed with Masonic rights.

The celebration terminated on the evening of the 20th with a banquet, at which Dr. Weir Mitchell presided as toastmaster. The speakers included the Governor of Pennsylvania, Samuel Pennypacker, *ex officio* patron of the American Philosophical Society, Senator Henry Cabot Lodge, Mr. Carnegie, M. Jusserand, Sir George Howard Darwin, &c.

It is the intention of your representatives to secure for the Institution of Mechanical Engineers such literature as may be published in commemoration of this notable event.

Respectfully yours,

Signed { Coleman Sellers.
Robert W. Hunt.
Ambrose Swasey.

CONVERSAZIONE.

A CONVERSAZIONE took place at the Institution on Friday, 11th May 1906, when the Members and their friends were received by the President and Mrs. Martin. During the evening the band of His Majesty's Scots Guards played a selection of music, and vocal music was rendered in the Library. Mr. C. Kadono showed some lantern slides, illustrating life in Japan, which was accompanied by short descriptions. The number of Guests was over 850.

MEMORANDUM FOR THE GAS-ENGINE RESEARCH COMMITTEE: METHOD OF DETERMINING THE TEMPERATURE AND THE RATE OF HEAT-PRODUCTION IN THE CYLINDER OF A GAS-ENGINE.

By Captain H. Riall Sankey, *Member*, of London.

[*Selected for Publication.*]

This note was prepared in February 1905 for the Gas-Engine Research Committee of the Institution of Mechanical Engineers.

In the following memorandum the attempt has been made to show how to determine the temperature at any point of the stroke, and the rate at which the heat due to the explosion of the charge is produced in the cylinder of a gas-engine. The method requires the use of the $\theta\phi$, or energy, chart for a gas, and the data needed are as follows, exemplified by a numerical example taken from the Second Report of the Gas-Engine Research Committee (Burstall's Trial D4):—

1	The heat of combustion of one kilogram* of the explosive mixture	461 calories.
2	The ratio of the specific heat at constant pressure to the specific heat at constant volume of the *explosive* mixture . . . . (γ)	1·39
3	The specific heat of constant volume of the products of explosion . . . . C_v	0·193
4	The specific heat at constant pressure of the products of explosion . . . . C_p	0·264
5	The indicator diagram	*See* Fig. 2 (p. 319).
6	The ratio of compression	5
7	The cylinder dimensions	12 ins. stroke. 6 ins. diameter.
8	The suction (or charge) temperature	128° C.

* Metric measures are used in the Second Report of the Gas-Engine Committee, Proceedings 1901, page 1031.

It is suggested that a certain number of the trials about to be carried out by Professor Burstall for the Gas-Engine Research Committee be analysed by the method.

The $\theta\phi$ chart * it is proposed to use has been drawn to a large scale, and a partial reproduction on a small scale is given in Plate 39.

The constant volume lines are the same whatever be the gas, this being effected by the artifice of varying the heat units per unit of area in proportion to the value of C_v, and varying the temperature scale as well according to the value of γ. For the present the constant volume lines are drawn on the supposition that C_v is constant. It is further to be observed that the horizontal intercept between a couple of constant volume lines is the same for all temperatures. A logarithmically divided scale can therefore be used, and by its means, and the single volume line for unit volume, any volume line can be drawn, or the volume at any given point can be determined. Unit volume is either the volume of 1 kg. of the gas at a pressure of 1 kg. per cm.^{2} at 0° C.; or the volume of 1 lb. of the gas at a pressure of 14·2 lbs. per square inch (approximately 1 atmosphere) at 32° F. The pressure lines vary, though not very greatly, with the value of γ as shown on the $\theta\phi$ chart. As in the case of the constant volume lines, the horizontal intercept between any pair of constant pressure lines is constant, and a logarithmically divided scale can be used to determine the pressure at any point, measuring from the line proper for the γ of the gas. For practical reasons the pressure lines for 20 kg. per cm.^{2} (or 284 lbs. per square inch) are the easiest to measure from in most cases. A portion of the 1 kg. per cm^2. lines is also given. Further particulars are given on the chart itself.

Fig. 2 is the *pv* diagram of a gas-engine (Burstall's Trial D4), and Fig. 3 (page 320) gives the corresponding $\theta\phi$ diagram, the point A being the point where the compression line cuts the atmospheric line. By an obvious calculation the pressure at A is found to be

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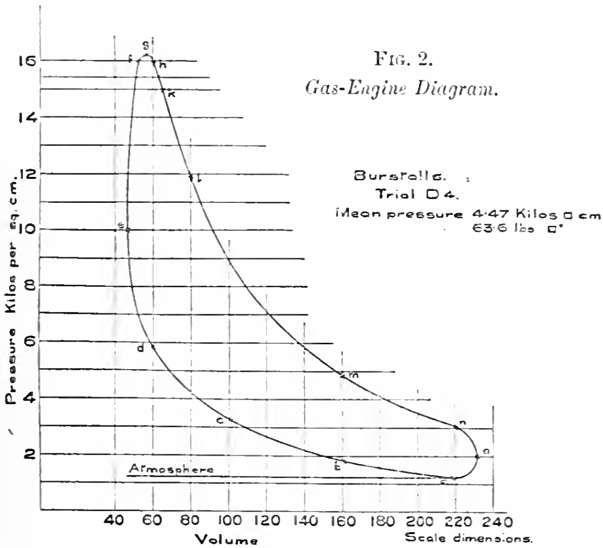
* It is thought that the $\theta\phi$ chart is now sufficiently well known not to require a detailed description.

0·96 kg. per cm²., and the suction temperature is 128° C. from Burstall's Trial. The $\theta\,\phi$ volume at the point A can therefore be found from the chart, taking $\gamma = 1 \cdot 39$ for the *explosive* mixture, and is found to be 1·56 units, and this corresponds to the maximum volume in the cylinder, represented by 232 scale divisions on the *pv* diagram. Therefore to plot the $\theta\,\phi$ diagram, the *pv* volumes must be multiplied by the ratio $\frac{1 \cdot 56}{232}$. This calculation has been made for the points *a*, *b*, *c*, etc., chosen along the contour of the

FIG. 2.
Gas-Engine Diagram.



pv diagram, and the result is given in Table 1 (page 325). From the data thus obtained the $\theta\,\phi$ diagram has been plotted as shown in Fig. 3 (page 320) by the dotted area (the points *a*, *b*, *c*, etc., are not shown).

The point C, which is at the end of the compression, can be fixed apart from the indicator diagram because the volume at C represents the volume in the clearance. Hence the volume at C is equal to the volume at A divided by the ratio of compression. In the numerical example—

$$\text{Volume at C} = \frac{1 \cdot 56}{5} = 0 \cdot 312 \text{ unit.}$$

Hence the position at C can be located on the chart at the intersection of the constant volume line (0·312 unit in this case) with the adiabatic through A. The temperature at the point C can be read off the chart, and in the numerical example is 420° C.

If, ideally, the explosion had been instantaneous, and there was no loss of heat to the jackets, or by radiation, the explosion line

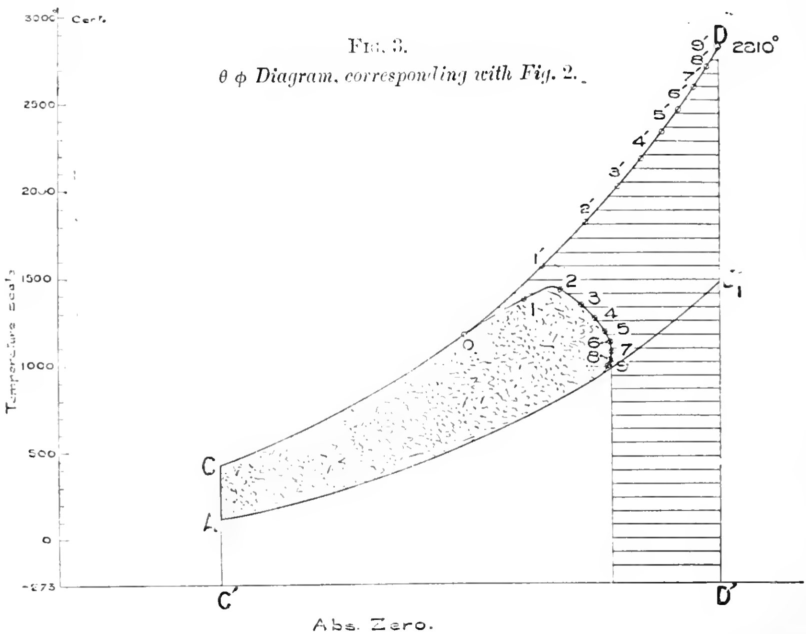


FIG. 3.
θ φ Diagram, corresponding with Fig. 2.

would have followed the constant volume line drawn through C until the point D was reached, such that the area C′CDD′ is equal to the heat due to the explosion, in this case 461 calories. The position of D is most readily obtained by calculation from the formula :—

$$\text{Temperature at D} = \frac{\text{calories due to explosion}}{C_v} + \text{Temperature at C}$$

$$= \frac{461}{0\cdot193} + 420 = 2{,}810^\circ\ \text{C}.$$

$ACDD_1$ is the $\theta\,\phi$ diagram of the ideal engine.

It will be seen that the figure $C'CDD'$ is divided into 3 areas:—

(*a*) The dotted area, which represents the heat utilized.

(*b*) The plain area, which represents the heat rejected in the exhaust.

(*c*) The area hatched with horizontal lines, which represents the heat lost to the jackets, by radiation and conduction during expansion and by incomplete combustion. The heat carried away by the jacket-water is however greater than this, as a certain amount of heat flows into the jacket during the exhaust stroke.

The thermal efficiency of the ideal engine is:—

$$\frac{\text{Area } ACDD_1}{\text{Area } C'CDD'}.$$

The thermal efficiency of the actual engine is:—

$$\frac{\text{Area of } \theta\,\phi \text{ diagram (dotted area)}}{\text{Area } C'CDD'}.$$

The efficiency ratio* is:—

$$\frac{\text{Area of } \theta\,\phi \text{ diagram (dotted area)}}{\text{Area } ACDD_1}.$$

The mean pressure in the cylinder can be obtained by the following formula, the data for which can be measured or read off the chart:—

$$\frac{\text{Area of } \theta\,\phi \text{ diagram} \times \text{calories per unit area} \times \text{Joule's equivalent.}}{\theta\,\phi \text{ volume swept by piston} \times \text{vol. 1 kg. gas at } 0^\circ \text{ C. and at 1 kg. per cm.}^2}$$

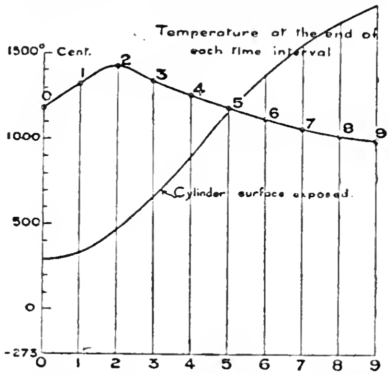
The pressures and temperatures at various points can also be read off the chart. The information thus obtained has been collected in Table 2 (page 326), and the corresponding figures from Professor Burstall's Trial D4 have been added by way of comparison.

By dividing the crank path into 20 equal parts, the volume in the cylinder at intervals of $\frac{1}{20}$th of the time of one revolution of the crank can be found by the usual graphic construction, taking account of the angle of the connecting-rod. These volumes

* *See* the Report of the Thermal Efficiency Committee of the Institution of Civil Engineers.

(reduced to $\theta\ \phi$ volume) are given in Table 3 (page 327). On plotting these volumes along the contour of the $\theta\ \phi$ diagram, the points 1, 2, 3, 4, 5, 6, 7, 8, and 9 are obtained. It will be seen that the exhaust opens at about the point 9; therefore the time during which heat flows into the jacket in respect of explosion and expansion is equal to 9 time intervals. The temperature at the points 1, 2, 3, etc., can be measured from the chart, and is plotted on Fig. 4, and the mean temperature occurring during the interval can be obtained, and is entered under column 2 of Table 4 (page 328). By deducting the temperature of the jacket-water,

FIG. 4.
Variation of Temperature during Stroke.

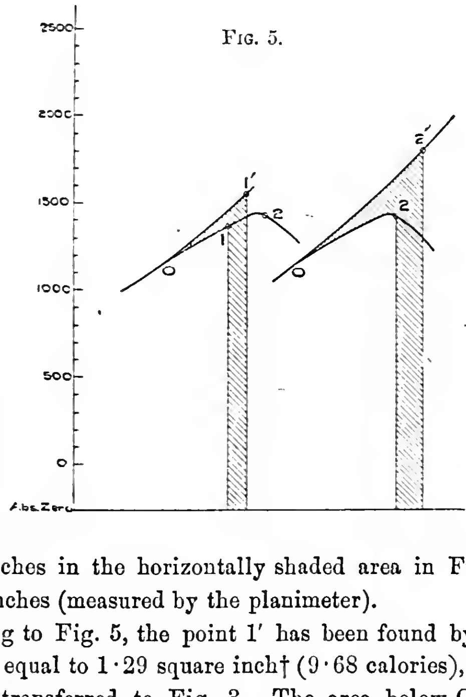


column 3 is obtained, and the flow of heat during each interval will be proportional to these differences of temperatures.

From the dimensions of the engine cylinder it is easy to calculate the surface exposed to the jacket at the end of each time interval, and the result is plotted on Fig. 4, from which the mean surface exposed during the interval can be found, and is entered under column 4 of Table 4 (page 328). The heat flow during the interval will be directly proportional to this mean surface; therefore the heat flow during any interval will be proportional to the product of the corresponding figures in columns 3 and 4, as given in column 5. The total of column 5 is 2,368,500, and this number represents the heat in the horizontally shaded area in Fig. 3, namely, 172 calories.

The figures given in column 6 are found by proportion, and are the calories transmitted to the jacket during each interval. The heat scale for the C_v taken for the example works out to 7·48 calories per square inch;* the heat flow to the jacket during each interval is therefore represented by the areas given in column 7. Obviously column 7 can be obtained direct from column 5 by reducing the figures in this column in the proportion of 2,368,500 to the number

Fig. 5.



of square inches in the horizontally shaded area in Fig. 3, namely, 23 square inches (measured by the planimeter).

Referring to Fig. 5, the point 1′ has been found by making the shaded area equal to 1·29 square inch† (9·68 calories), and the point 1′ has been transferred to Fig. 3. The area below C1′ represents the heat produced in the engine cylinder up to the end of the first time-interval, and the area below CO1 represents the corresponding heat shown by the indicator diagram. The difference between these two

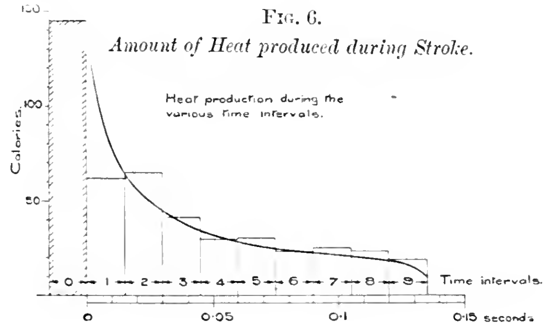
* This number refers to the large scale energy chart mentioned on page 318. The heat scale for Fig. 1, Plate 39, is approximately 120 calories per square inch.

† On the large scale chart.

amounts of heat, namely, 9·68 calories, might be termed the "missing heat," corresponding to the missing quantity in the case of a steam-engine. The position of the point 2′ can be found in the same way as shown in Fig. 5 by making the shaded area equal to the sum of the first two items in column 7, Table 4 (page 328), namely, 1·29 + 1·61 square inch.

Fig. 6.

Amount of Heat produced during Stroke.



As already mentioned, the area below C1′ represents the heat produced during the first time-interval, and this heat can be calculated from the formula :—

Calories produced up to the end of first interval

$$= C_v \text{ (temp. at } 1' - \text{temp. at C.)}.$$

The same process has been carried out for the remaining points, and in this way the points marked 1′, 2′, 3′, 4′, 5′, 6′, 7′, 8′, 9′, on the constant volume line CD (Fig. 3) have been obtained, and the calories produced up to the end of each interval have been calculated and entered in Table 5 (page 329). Obviously the calories produced *during* each interval can be found by subtracting the calories produced up to the end of one interval from those produced up to the end of the next, as given in the last column of Table 5. The calories produced per interval have been plotted in Fig. 6. A curve has been drawn approximately through the middle points of the steps, and is sensibly the curve that would have been obtained if the intervals had been very numerous. This curve represents, therefore, the rate of heat production during the explosion, and gives the information desired.

The result obtained shows that a considerable amount of heat is produced not only after the piston has begun to move, but even quite late in the stroke. Other examples that have been worked out show a greater proportion of heat produced at the beginning of the stroke. It must also be remembered that the constant-volume lines on the chart have been drawn on the supposition that specific heat is constant, and an increase in the specific heat would tend to show a greater production of heat at the beginning of the stroke. The proposed method, however, would not be affected by this alteration in the constant-volume line.

TABLE 1.

Point on Indicator Diagram.	Volumes.		Pressure Kg. per cm.^{2}	Remarks.
	pv Scale Divs.	$\theta\ \phi$ Unit Volume of Chart.		
a	218	1·467	1·18	These figures are not plotted, as the compression line does not concern the present enquiry.
b	160	1·077	1·80	
c	100	0·674	3·28	
d	60	0·404	5·80	
e	47	0·317	10·00	
f	53	0·359	16·00	
g	57	0·384	16·22	
h	60	0·404	16·00	
k	65	0·438	15·00	
l	80	0·539	11·86	
m	160	1·077	4·86	
n	220	1·482	3·04	
o	232	1·562	2·00	

NOTE.—The volumes 232 and 1·562 correspond to the volume in the cylinder at the end of the stroke, and the volumes 47 and 0·317 correspond to the clearance volume.

TABLE 2.

	Temperatures Centigrade.				Pressures, Kg. per cm.²			Thermal Efficiency.		Efficiency Ratio E.R.	M. P. Kg. per cm.²
	Suction.	Compression.	Maxm.	Exhaust.	Compression.	Maxm.	Exhaust.	Ideal.	Actual.		
$\theta\phi$ diagram, Fig. 3, p. 320.	128	420	1,440	980	8·5	17·0	3·0	0·45	0·21	0·53	4·7
Burstall's Trial, D 4.*	128	429	1,454	887	8·7	14·41 dia-gram shows 16·2	2·9	—	0·221	—	4·47

* Proceedings 1901, October, pages 1076–1081.

TABLE 3.

Point of the Stroke (Out Stroke).	$\theta\ \phi$ Volume.	Surface exposed at the end of each time-interval.
0	0·312	101·6
1	0·345	109·1
2	0·455	134·2
3	0·612	169·4
4	0·801	212·2
5	1·000	266·2
6	1·187	299·8
7	1·342	334·6
8	1·440	359·4
9	1·534	378·0
10	1·560	384·2

TABLE 4.

1	2	3	4	5	6	7
Time-Interval.	Average Temperature during Interval.	Col. 2, less Mean Jacket Water Temp. (40° C.)	Mean Surface exposed during Interval.	Product of Cols. 3 and 4.	Calories transmitted to Jacket during Interval.	Square Inches on large scale Chart corresponding to Calories (Col. 6).
0–1	1,320	1,280	104	133,300	9·68	1·29
1–2	1,420	1,380	120	165,600	12·04	1·61
2–3	1,370	1,330	151	200,800	14·55	1·95
3–4	1,280	1,210	190	235,800	17·13	2·29
4–5	1,230	1,190	239	284,500	20·68	2·76
5–6	1,150	1,110	283	314,000	22·80	3·05
6–7	1,090	1,050	320	336,100	24·41	3·27
7–8	1,020	980	348	342,200	24·88	3·33
8–9	1,000	960	371	356,200	25·90	3·46
			Totals . .	2,368,500	172·07	23·01

TABLE 5.

Point on Constant Volume Line of Theoretical Explosion.	Temperature at each Point. C°.	Time-Interval.	Total Calories produced up to the end of each Interval.	Calories produced during each Interval.
0′	1,200	Instantaneous	145	145
1′	1,490	0–1	207	62
2′	1,830	1–2	272	65
3′	2,040	2–3	313	41
4	2,190	3–4	342	29
5′	2,350	4–5	372	30
6′	2,470	5–6	395	23
7	2,600	6–7	420	25
8	2,720	7–8	443	23
9′	2,820	8–9	462	19

The Memorandum is illustrated by Plate 39 and 5 Figs. in the letterpress.

MEMOIRS.

Andrew Betts Brown was born in Edinburgh on 4th May 1841. He was educated in that city, and served his apprenticeship in the locomotive works of the North British Railway at St. Margaret's. During this period he attended the evening classes at the Watt College, where he gained several prizes in Natural Philosophy and Dynamics. He then went to Manchester, and studied chemistry and kindred subjects at a technical college, taking various degrees. In 1863 he proceeded to London, and purchased an old brewery, which he converted into engineering works, still existing under the name of the Vauxhall Iron Works. One of his early inventions was that of an overhead travelling-crane, which was used with success in the construction of Blackfriars Bridge. In 1870 he obtained an important contract to fit Hamburg Docks with a plant combining steam and hydraulic power for discharging ships, which he had then just brought out. Part of this plant was constructed in London, but realising that conditions were more favourable in Edinburgh, he acquired some ground at Rosebank, adjoining the North British Railway Co.'s line to Granton, and the necessary plant was erected to complete the Hamburg contract. Since then these works have been so extended that they are now one of the largest engineering works in the east of Scotland. His next invention, and perhaps the best known, was the combined hydraulic and steam starting-engine which is now used in nearly every large and small steamer afloat. He next devoted his attention to marine engineering, and was one of the first to take up the problem connected with the steering of large vessels. He invented the steam-tiller, which at its time was quite a novelty, and which has been adopted by the majority of the present larger ships both naval and commercial. In connection with this he also devised the telemotor, a hydraulic apparatus designed to facilitate the control of the stearing gear from the bridge, by dispensing with the cumbersome chains and shafting which had been hitherto used.

Among his other numerous inventions was the well-known hydraulic installation for loading and discharging cargoes, involving the use of the well-known steam-accumulator, of which he was the originator, and on which subject he read a Paper * before this Institution in 1874. This mode of discharging cargoes is now used extensively by the Royal Mail and British India Companies. He brought out a new form of forging press combining his steam-compressor, for dealing with heavy marine shafting and gun forgings. A large number of the Japanese Fleet was steered by his machinery, and his firm have supplied steering gears for the latest Japanese battleships and the two latest express Cunard steamers—Lusitania and Mauretania. His death took place at his residence in Edinburgh, on 13th May 1906, at the age of sixty-five. He became a Member of this Institution in 1866; he was also a Fellow of the Royal Society of Edinburgh, and a Member of the Institution of Naval Architects.

WILLIAM CRAVEN was born at Bradford, Yorkshire, on 8th August, 1829. In his early youth he went to Manchester, and served his apprenticeship with Messrs. Sharp, Roberts and Co.; on its completion he was employed at Messrs. Fairbairn's Works. In 1853 he commenced business in partnership with his brother—Mr. Greenwood Craven—as machine-tool makers at Dawson Croft Mill, Salford. The requirements of the business very soon necessitated removal to larger premises in Manchester, where they were joined by their brother—Mr. John Craven. In consequence of a still further and rapid increase in the demand for their high-class machine-tools, land was bought in 1863 and new works were built in Osborne Street, the site of the present works. In the development of the business each of the three brothers assumed responsibility for one particular portion of it, William Craven taking charge of the designing of the various machines constructed by the firm, and in this department he made his name famous in the engineering profession. In 1875 the manufacture of cranes was taken up, and so great has this branch grown that in 1900 new

* Proceedings, 1874, page 33.

works were built at Reddish, near Stockport, specially equipped for their manufacture together with that of modern machine-tools. In 1885 the firm was transformed into a limited company, with Mr. Greenwood Craven as chairman, who was succeeded on his death in 1889 by Mr. William Craven. He retained this position until advancing age and failing health led him to resign in 1903, when his son—Mr. W. H. S. Craven—was elected chairman. He took little part in public affairs, but devoted his time and abilities to his profession. His death took place at his residence at St. Anne's-on-Sea, Lancashire, on 10th May 1906, in his seventy-seventh year. He became a Member of this Institution in 1866.

James Brown Edmiston was born at Greenock on 24th October 1844. He served his apprenticeship of five years at the Shaws Water Engineering Works of Messrs. McNab and Co., Greenock, and passed the various examinations requisite for a sea-going engineer. He then went to India as chief engineer for the P. and O. Co., and while there transferred his services to the British India Co. After remaining abroad seven years he returned to this country, and became engineering superintendent for Mr. Joseph Hoult, of Liverpool. In 1882 he joined the firm of Messrs. Hamilton, Fraser, and Co., as consulting and superintending engineer, and remained with them until his death. He invented a feed-water filter, and was associated with the late Mr. Mudd,* of the Central Marine Engine Works, West Hartlepool, in the introduction of the quadruple-expansion engine operated on the five-crank principle. His death took place at his residence at Walton, Liverpool, on 8th May 1906, in his sixty-second year. He became a Member of this Institution in 1883.

Henry Dickenson Marshall was born in Manchester on 5th May 1840. When quite an infant he was taken to St. Petersburg, where his father—Mr. William Marshall—had an appointment. At six years of age he returned to England and began his school-life in Manchester. Two years later his father

* Proceedings 1898, page 538.

purchased a small engineering and general millwright's business in Gainsborough, and the son completed his education in that town, starting in the works as an apprentice at the early age of thirteen. Operations were at first conducted on a very small scale, but eventually $1\frac{1}{2}$ acres of land were purchased, and on this the nucleus of the present works was erected in 1855–56. In the following year Mr. James Marshall, the eldest son, became a partner of his father, the firm being then styled William Marshall and Son, a title which was changed to William Marshall and Sons four years later, when Mr. Henry D. Marshall was also taken into partnership. Before he was twenty-one his father died, and eighteen months later, in 1862, the business was formed into a private company, with Messrs. James and Henry D. Marshall as joint managing directors. In those days Gainsborough was a small country town, whose principal industry—the building of small ships—was decaying. Today Messrs. Marshall's Works employ no less than one-fifth of the total population of the town, which has trebled itself within the history of the firm. Originally devoted to the construction of small agricultural engines, thrashing machines, etc., the firm now turn out stationary engines of over 1,000 horse-power. Altogether over 80,000 engines have been produced at these works, and about a similar number of boilers of all kinds. Other large departments deal with the manufacture of tea-preparing machinery, grinding mills, gold-dredging plant, etc.

He was deeply interested in technical education, and the firm co-operated with the County Council in the provision of qualified teachers at the large class-rooms and art studios built in connection with the works. In local affairs he took a keen interest, and had been a member of the County Council since its formation in 1899, and a Justice of the Peace from 1892. He was elected a Member of this Institution in 1885, the same year in which the Summer Meeting was held in Lincoln, and on that occasion his firm entertained the Members on their visit to Gainsborough. In 1889 he was elected a Member of Council, which position he held continuously until near the close of last year when the state of his health led him to resign. He was also on the Councils of the

Royal Agricultural Society and the Agricultural Engineers' Association, being a Past-President of the latter body. His death took place at his residence in Gainsborough, on 8th March 1906, in his sixty-sixth year.

WILLIAM PRIME MARSHALL was born at St. Albans on 28th February 1818. He received an excellent home education from his father, which was supplemented later by the lectures of Professor Edward Cowper in the engineering department of King's College, London. He entered Mr. Robert Stephenson's office on the London and Birmingham Railway in 1835 during the construction of the line, and on completion of the railway was transferred to his Westminster office. Under Mr. Stephenson's directions he made a series of experiments on rope traction upon the Euston incline, and assisted in a set of experiments on the deflection of rails made upon the Great Western Railway. In 1839 he was engaged under Mr. Stephenson upon the plans for the North Midland Railway stations, and afterwards had charge of the construction of those stations, in conjunction with the architect, Mr. Francis Thompson. At the opening of that railway he was appointed locomotive superintendent of the line, and held this office until the amalgamation in 1843 with the present Midland Railway. In 1884 he carried out, in conjunction with the late Mr. George Berkley, a series of experiments upon the Dublin and Kingston Atmospheric Railway for Mr. Stephenson's report to the Chester and Holyhead Railway Co., and subsequently they carried out, also under Mr. Stephenson, the alteration of the gauge of the Eastern Counties Railway from 5 feet to 4 feet 8½ inches, for the purpose of effecting a continuous connection with the other railways of the country. In 1845 he was engaged upon the plans for the stations on the Norfolk Railway, under Mr. Stephenson, and, on the opening of that line, was appointed resident engineer and locomotive superintendent, continuing in that position until the amalgamation with the Great Eastern Railway in 1848.

He joined this Institution as a Member in October 1847, the year of its formation, and on 24th January 1849 he was elected

Secretary under the presidency of Mr. Robert Stephenson. This position he held for twenty-nine years, until the removal of the Institution to London, his energetic and active management greatly contributing to its success. During this period he presented two Papers to the Proceedings, namely, "On Berdan's Crushing and Amalgamating Machine," * and "On the principal constructions of Breech-Loading Mechanism for Small Arms, and their relative mechanical advantages." † He was joint honorary secretary with the late Mr. George Shaw of the Birmingham Industrial Exhibition, held in connection with the meeting of the British Association for the Advancement of Science in 1849, and he also took charge of the Birmingham exhibit in the International Exhibition of 1851. In the following year he was joint secretary, with the late Mr. W. Matthews, of the committee which originated and carried out the formation of the Birmingham and Midland Institute. In conjunction with the late Mr. Edward Woods, he carried out in 1853 an important investigation into the locomotive working of the London and North Western Railway, with an extensive series of trials of different locomotives. He acted in 1854, and subsequently in partnership with his son, Mr. W. Bayley Marshall, as Inspecting Engineer to the Crown Agents for the Colonies, in the inspection of locomotives and carriages for many colonial railways. In consequence of great alterations made in the Crown Agents' Office, this arrangement was determined in 1904. Among local societies with which he was identified was the Birmingham Natural History Society, of which he was joint honorary secretary from 1887. In 1863 he was awarded the silver medal of the Society of Arts for a Paper on "Automatic Brakes," and in 1896 he received the George Stephenson Medal and a Telford Premium awarded by the Institution of Civil Engineers for a Paper on "The Evolution of the Locomotive." His death took place at his residence at Edgbaston, Birmingham, on 27th March 1906, at the age of eighty-eight.

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* Proceedings 1854, page 33.

† *Ibid.* 1871, page 92.

Jeremiah Eugene Mathewson was born at Peterborough, New York State, United States, in October 1841. He was educated at the University of Wisconsin, and afterwards entered a large works where he passed through the various shops and the drawing office. The outbreak of the Civil War in 1861 infected him with zeal for the cause of the North, and he offered his services to the government, which were accepted. He was drafted into the artillery, and for three years served with the guns. On leaving the army at the close of the war, he returned to his engineering work, and in 1869 was engaged by Messrs. B. C. and R. A. Tilghman, of Philadelphia, as an assistant, experimenting in mechanical and chemical work. Shortly after the commencement of the engagement, Mr. B. C. Tilghman originated the idea of the sand-blast, and the construction of the first apparatus was entrusted to Mr. Mathewson. He assisted in the subsequent trials of the invention, and, after its development, was sent over by the firm, in 1873, to England, for the purpose of exhibiting the process at South Kensington. The introduction of the apparatus was so successful that it was decided that he should take up his residence permanently in England, and in the following year the Tilghman's Patent Sand-Blast Co. was formed in London, where he lived for several years, becoming a naturalised British subject. In 1877 he was appointed managing director, a position which he held up to the time of his death. He considerably improved and developed the process, and many patents were taken out by him in connection with it. The establishment of the works in Sheffield in 1880 eventually led to a large extension of trade. For a long time after its introduction, the sand-blast was practically confined to obscuring and decorating glass, and later to the re-sharpening of worn and half-used files, etc. Within recent years it has been adopted for cleaning castings and removing scale from iron and steel surfaces preparatory to galvanizing, plating, and other processes.

In 1896 the company was amalgamated with that of Messrs. Richards and Co., of Broadheath, Manchester, and Mr. Mathewson, who had for some years been a director of the latter company, became managing director of both concerns, and the sand-blast process was removed from Sheffield to Broadheath. He completely

reorganised these works, introducing electric power for steam, and building a new erecting shop and foundry. In local matters he took a great interest, and was a member of the Altrincham Urban District Council from 1898 to 1901, when he resigned in consequence of pressure of business engagements. For some little time his health had been failing, and his death took place at his residence in Altrincham, on 31st May 1906, in his sixty-fifth year. He became a member of this Institution in 1891.

JOHN WILLIAM McCOOL was born at Plumstead on 4th March 1866, and was educated at the Roan School, Greenwich. On leaving school in 1881 he went to Brisbane, Queensland, where his father was in business, and assisted him as an engineer and machinery importer. From 1882 to 1889 he served an apprenticeship at the works of Messrs. Smith, Forrester and Co., Brisbane, and passed through the various shops. On its completion, he was employed as a supernumerary engineer in the Harbours and Rivers Department of Queensland, and then went to Charters Towers, where he undertook contracts for dismantling and re-erecting machinery at the gold mines. Owing to the great depression in trade following the serious floods in Queensland, he returned to England in 1890, and obtained employment in the erecting shop of Messrs. Merryweather and Sons, Greenwich. In 1891 he went to South America as erector and engineer at the new metallurgical works of the Compañia Huanchaca de Bolivia, and, on the completion of this contract in 1894, he returned to England. He next obtained an appointment in Bombay as manager for Messrs. G. Hill and Co., machinery importers and engineers, and subsequently became a partner. Owing to depression in business the partnership was dissolved in 1902, and he took up temporarily the work of inspecting fire appliances for the Bombay Fire Insurance Agents' Association. Later, he received the appointment of inspector and surveyor to the Calcutta Fire Insurance Agents' Association, holding this position to the time of his death, which took place from small-pox at Calcutta on 15th March 1906, at the age of forty. He became an Associate Member of this Institution in 1905; and was also a Member of the British Fire Prevention Committee.

James McFarlane was born in Lauder, Berwickshire, on 9th November 1841, and received his education at Gordon School, near his native place. From 1855 to 1860 he served an apprenticeship as a millwright and engineer, partly with the late Mr. J. Young, St. Leonard's, Edinburgh, and partly with the late Mr. Samuel Easton, Engineer, Fushiebridge, Midlothian. From 1860 to 1864 he worked as a journeyman fitter in various engineering establishments in Edinburgh, Glasgow, and Leith. In 1864 he was appointed foreman in the engineering works of Messrs. S. and H. Morton, engineers and shipbuilders, Leith, where he remained for two years engaged in superintending the construction of marine engines and other steamship machinery. Two years later he received the appointment of under-foreman, and subsequently became principal foreman in the Edinburgh works of Messrs. G. and W. Bertram, engineers and manufacturers of paper-making machinery. There he remained for eight years, during which time he was actively concerned in the introduction of many reforms in workshop practice, and was also instrumental in improving the design and construction of steam-engines and paper-making machinery in various details.

In 1874, he, together with a partner, commenced business in Edinburgh under the title of Kay and McFarlane, engineers and ironfounders, which was ultimately dissolved ten years later. During that decade he made a special study of the requirements of brewery and distillery machinery and plant, earning a reputation for his extensive knowledge, and securing several patents for inventions and improvements connected with this branch of engineering. About the same period he also turned his attention to the improvement of apparatus for the conveyance of grain in warehouses, malt-houses, &c., by means of endless belts, and was entrusted with the installation of examples of this class of machinery in many of the leading breweries and distilleries in the United Kingdom, all which proved to be a great saving of labour and time as compared with methods of grain transportation previously practised. In 1884 he joined, as partner, the firm of Messrs. James Milne and Son, engineers, Edinburgh, and shortly after superintended the erection and equipment of large new workshops for his firm. In these works

a larger field was opened up for his capabilities in carrying on the manufacture of paper-making machinery, brewery and distillery plant, and general engineering. At this period he also brought out several inventions and improvements connected with paper-making and brewing machinery. In 1891 he severed his connection with Messrs. Milne and Son, in order to commence practice as a consulting engineer in Edinburgh, making a speciality of brewery and distillery work; and continued in active practice until within two years of his death. During this period he carried through many alterations and reconstructions of existing breweries, etc., and also superintended the complete construction and equipment of several new works of a similar kind. He was a Fellow of The Royal Scottish Society of Arts, a life-member of The Edinburgh Association of Science and Art; and was associated with several other scientific institutions connected with the Scottish capital. In 1904 he retired from business on account of failing health, and his death, from heart failure, occurred at Edinburgh on 21st May 1906, in his sixty-fifth year. He became a Member of this Institution in 1895.

VITALE DOMENICO DE MICHELE, son of the late Mr. C. E. de Michele, was born on 11th November 1848, in Westminster, where his father owned and edited the "Morning Post." At an early age he was sent to Westminster School, where he remained until he was sixteen, when he was apprenticed to Messrs. Robert Stephenson and Co. at the South Street Engine Works, Newcastle-on-Tyne. During this time he invented a form of reversing gear which has been largely used in looomotives and marine-engines. Having passed through the various shops and drawing offices, he was selected, at the age of nineteen, as the representative of the firm in charge of their exhibits at the Paris Exhibition in 1867. At this time it was his great desire to follow up either locomotive or marine engineering, but his father, who had retired from the consular service and had acquired an interest in the Nine Elms Cement Works, near Gravesend, required his services as works manager. There he worked very hard in developing the growing business, and designed new buildings,

wharves, kilns, and mills for the manufacture of cement. Having thoroughly mastered the process of cement-making, he set to work to make improvements in each step of the manufacture, which resulted in the producing of more uniform qualities, of higher strength and endurance, whilst the economies he introduced tended to lower the selling prices and to bring cement into more general use. Among the improvements effected may be mentioned a wash-mill which had a raised rim of cast-iron plates surmounted by revolving plates, which would not allow the cement to pass through until it had been ground sufficiently fine. As the cement had not to pass through gauze, it was possible to wash it with one-third of the quantity of water formerly employed. It was then pumped through cast-iron mains direct to the drying floors, thus eliminating the cost of settling ponds, the labour of digging and wheeling, and the capital cost of a large area of land. To economise fuel, he designed kilns in which the waste heat, instead of going direct to the atmosphere, passed under the cast-iron and brick arch drying-floors. About 1871 he recognised the need for more reliable tests, and he invented the increasing leverage cement-testing machine, and later eliminated vibration by actuating the lever hydraulically. He also brought to a successful issue the manufacture of cement on a continuous principle, after the manner of the paper-making machine. So carefully did he conduct his chemical and mechanical tests of cement that he brought up the quality to the high pitch required for rock lighthouses. He took a practical interest in the smoke question, and invented a stove and fireplace with rotatory churn bottom bars, by which coal or coke were put in behind the fire, which thus always had a bright front and made no visible smoke. In addition to managing the works at Gravesend he carried on a consulting practice at Westminster, and among the works with which he was connected were the water-supply of Higham and Aylesford in Kent, the construction of wharves at Rochester, Greenhithe, and Strood, and the strengthening of the movable span of Rochester Bridge under the late Sir Joseph Bazalgette, at whose death he was appointed consulting engineer for the work. He was a Justice of the Peace for Kent. His death took place at his

residence, Higham Hall, near Rochester, on 21st March 1906, in his fifty-eighth year. He became a Member of this Institution in 1877; and he was also a Member of the Institution of Civil Engineers.

HENRY JAMES TAYLOR PIERCY was born in Birmingham on 2nd January 1842. He served an apprenticeship at the engineering works of Messrs. Phillips, of the same city, and commenced business on his own account in 1863 at the Minerva Works, Broad Street, Birmingham. In 1874 he removed to the Broad Street Engine Works, carrying on an increasing business as engineers, iron and brass founders, etc. The firm was converted into a company in 1905, of which he became chairman, with his son—Mr. G. F. Piercy—as managing director. For thirty-five years—1870 to 1905—he also practised as a consulting engineer and valuer, and for fifteen years was consulting engineer to the Corporation of Birmingham. Among the inventions he brought out may be mentioned those of shaft carriers, automatic governors for stationary steam-engines, and improved pneumatic planishing hammers, etc. His death took place at his residence at Moseley, near Birmingham, on 24th April 1906, at the age of sixty-four. He became a Member of this Institution in 1876.

SAMUEL RENDELL was born at Clifton, Bristol, on 3rd November 1857, and was educated at Chesterfield Grammar School. His apprenticeship was served in the shops and drawing office of Messrs. R. and W. Hawthorn, Leslie and Co., Newcastle-on-Tyne. While there, in 1876, he obtained a local scholarship at the evening classes of the Newcastle Mechanics' Institute which enabled him to attend the day classes in engineering at Owens College, Manchester, where he remained four years. In October 1880, he entered the drawing-office of Messrs. Beyer, Peacock and Co., of Gorton, as junior draughtsman, rising to be assistant chief draughtsman and finally to chief draughtsman. His mathematical knowledge frequently found application in mechanical scheming and solving problems of locomotive design. His death took place at New

Mills, near Stockport, on 29th March 1906, at the age of forty-eight. He became a Member of this Institution in 1890; and he was also a Member of the Manchester Association of Engineers.

Sir THOMAS RICHARDSON was born at Castle Eden on 28th December 1846, and was the son of Mr. Thomas Richardson who represented the Hartlepools in Parliament for many years. After graduating at Cambridge, he left the University in 1868, to assist his father in the management of the Hartlepool Engine Works which had gained a great reputation for their marine engines. The name of the firm was intimately connected with the development of the triple-expansion marine engine, and a large business was done in converting compound-engines to triple-expansion. On the death of his father in 1890, the management of the business devolved on Sir (then Mr.) Thomas Richardson and his brother, Mr. W. J. Richardson. Ten years later the firm was amalgamated with Messrs. Westgarth, English and Co., of Middlesbrough, and Messrs. William Allan and Co., of Sunderland, the combination taking the name of Richardsons, Westgarth and Co., and having Sir Thomas as vice-chairman, a post which he held until his death. Besides his duties in connection with his business, he took a great interest in local and imperial affairs. He was Mayor of Hartlepool in 1887 and 1888, and a member of the County Council for several years. In 1895 he was elected Member of Parliament for the Hartlepools, and sat until 1900. He was knighted on the occasion of the Jubilee of the late Queen in 1897, and was presented with the freedom of Hartlepool in the same year, on account of his great services to the town. He became a Member of this Institution in 1887, and was elected a Member of Council in 1899. When the Institution held its Summer Meeting at Newcastle-on-Tyne in 1902, and visited the Hartlepools, he was chairman of the local reception committee at those towns, and much of the success of the visit was due to his organising ability and energy; and on the occasion of the Middlesbrough Meeting in 1893 he assisted on the Hartlepool Reception Committee and welcomed the Members at his works. He was prominent in all things connected with the welfare of friendly

societies and hospitals, and encouraged sport in many ways. He was chairman of the Manchester and Salford Shipping Co.; the High-Speed Stamp Co.; and a director of the Northern Counties Electrical Supply Co. His death occurred, after an illness of some duration, at his residence at Kirklevington, near Yarm, Yorkshire, on 22nd May 1906, in his sixtieth year.

JAMES SCARLETT was born at Methley, Yorkshire, on 26th January 1821. He commenced his engineering career, at the age of fourteen, with the late Mr. Edward Green, of Wakefield, engineer and millwright, and was closely associated with him in the introduction of the Green fuel economiser. He represented the firm and had charge of their exhibits at the great Exhibition of 1851. On the conversion of the business into a private company in 1891, he was appointed a director, being head of the commercial department where he was brought prominently into contact with many of the principal firms of Lancashire and Yorkshire and the Continent. In 1899 he retired from active participation in the business. His death took place at Bowdon, Chechire, on 23rd September 1905, in his eighty-fifth year. He became a Member of this Institution in 1869.

PERCYVALE TAYLOR was the son of Mr. Richard Taylor of the old-established mining firm of John Taylor and Sons, London, and was born near Falmouth on 4th February 1847. After a home education he studied mechanical engineering in the works of Messrs. T. B. Jordan and Sons, in South London, and in 1867 undertook the management of the lead smelting and desilverizing works of the Société des Mines et Fonderies de Pontgibaud in the Auvergne, France. In 1872 he resigned this position, and was then appointed manager of the Panther Lead Works at Bristol. In 1882 he was sent by his father's firm to inspect and report upon a series of mines in Arizona. Relinquishing the direction of the Panther Lead Works in 1883, he again undertook the inspection of mines in the United States, principally in the Rocky Mountains. In the following year he entered into partnership with M. P. Burthe, of Paris, as mining engineers, the firm undertaking the management of the tin mines of

La Villeder in Brittany, Bonnac in Auvergne, and others, and at the same time the inspection of mines in France, Spain, and other countries. On behalf of his firm he went out to the State of Perak, Straits Settlements, to explore, prospect, and take up tin-mines, and several concessions were taken up and worked by the firm, under his management. After spending about three years there he returned to Europe and retired from active business. His death took place at his residence in London, on 19th April 1906, at the age of fifty-nine. He became a Member of this Institution in 1874.

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1906.

Parts 1–2.

Fig. 8. *Shearing Shackles (open) showing Specimen.*

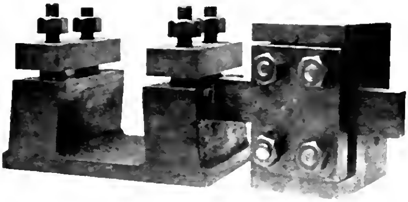


Fig. 10. *Shear Fracture of Cast-iron.*

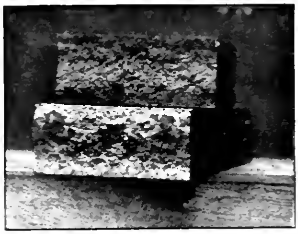


Fig. 9. *Shear Apparatus in Testing Machine.*

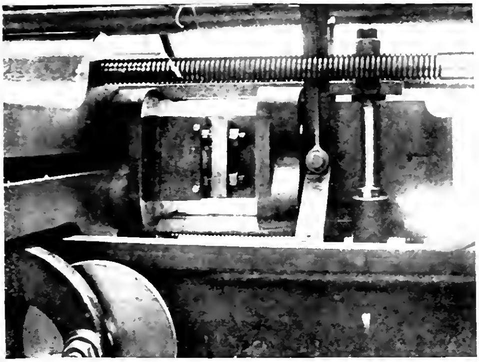


Fig. 11. *Shear Fracture of Mild-Steel*

Fig. 12. *Partly Sheared Specimens of Mild-Steel.*

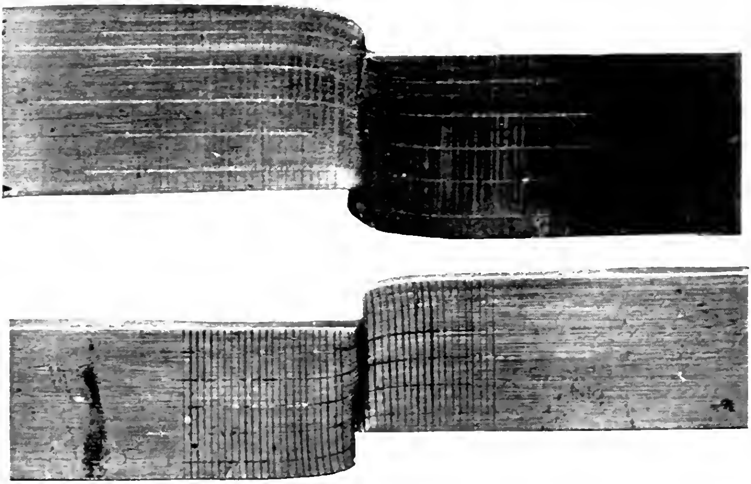


Fig. 13. *Shear Fracture of Cast Aluminium-Bronze.*

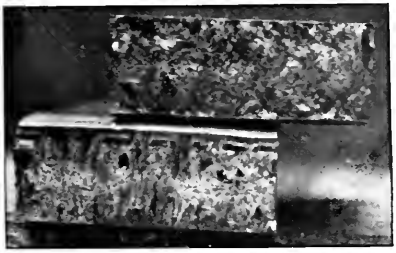


Fig. 14. *Shear Fracture of Aluminium Alloy (No. 4).*

Fig. 15. *Shear Fracture of Delta Metal.*

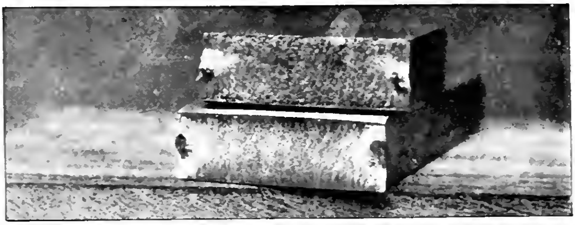


Fig. 16. *Shear Fractures of Teak (across grain).*

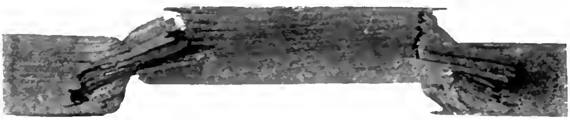
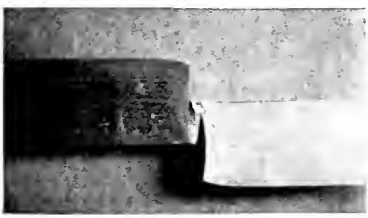


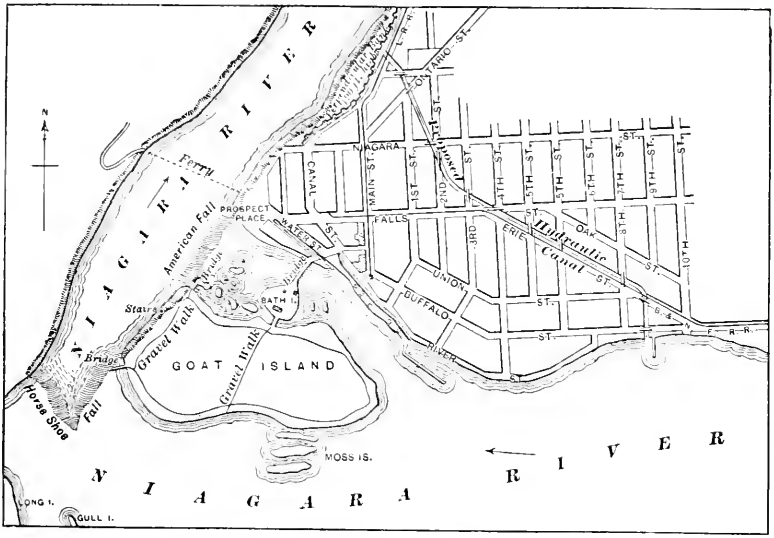
Fig. 17. *Shear Fractures of Phosphor-Bronze.*

Ordinary.

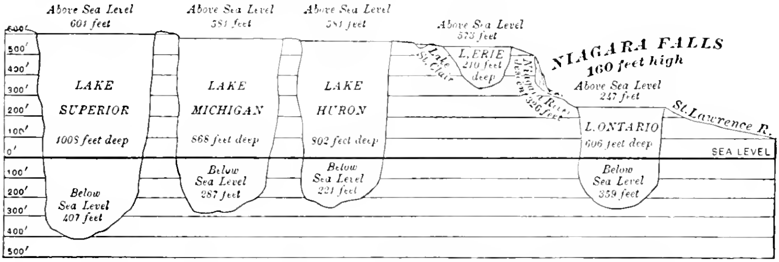


Specially Treated.

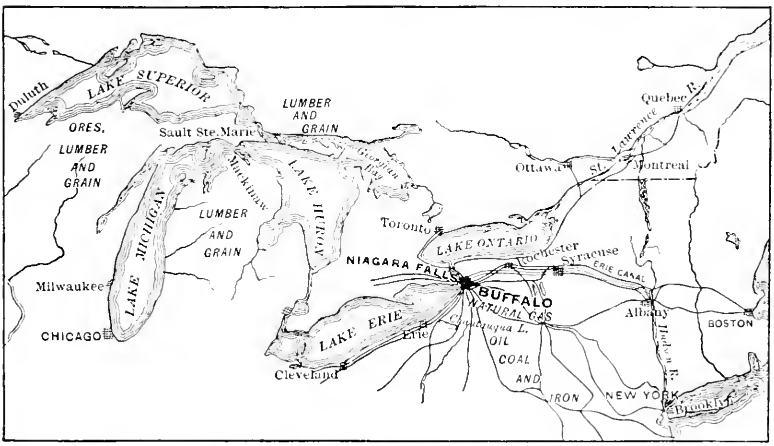
Peter Emslie's Map, showing the Early Canal and Reservoir proposed in 1846.



Depths and Levels of the Great Lakes.

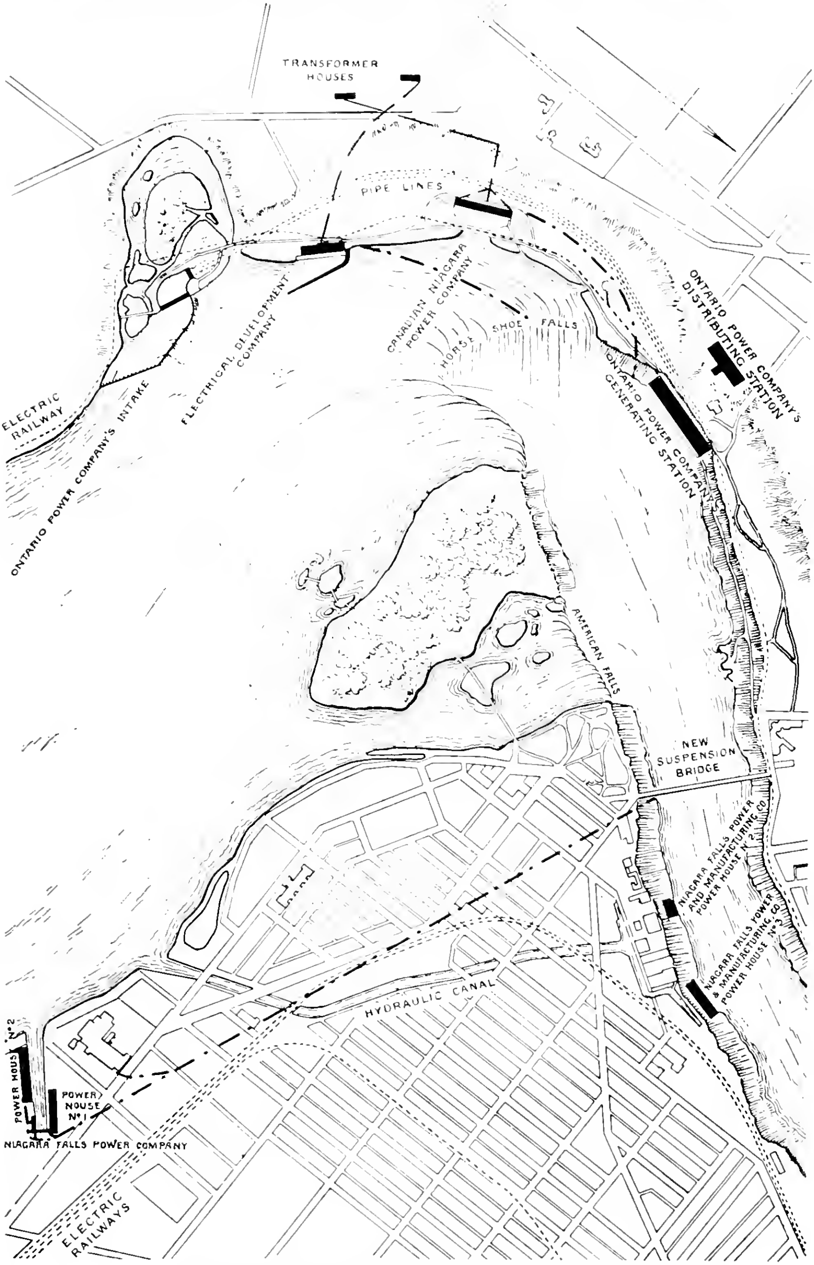


Buffalo showing its Water and Railway Connections.



NIAGARA FALLS POWER-STATIONS. *Plate 4.*

Map of Niagara Falls showing location of Power Developments.



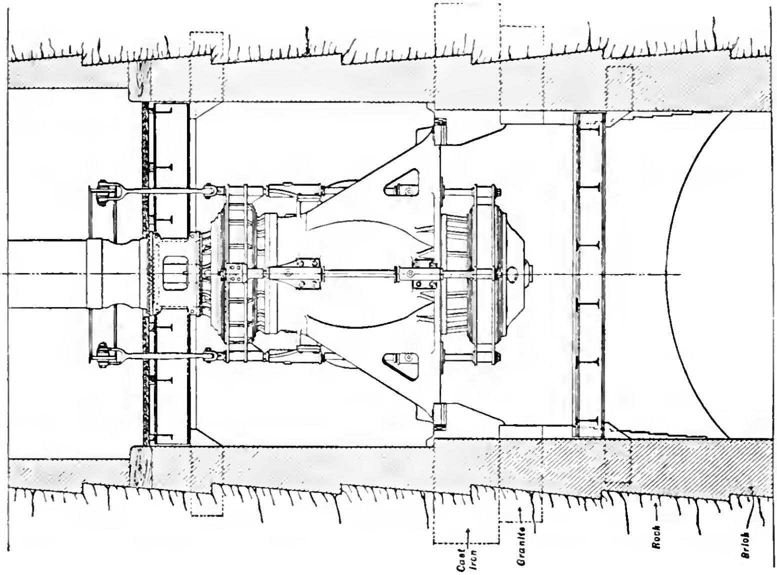
TAIL-RACE TUNNELS — · — · —

Niagara Falls Power Co. (7,000 ft.), discharges at New Suspension Bridge.
Electrical Development Co. (1,900 ft.) ,, ,, Centre of Horseshoe Falls.
Canadian Niagara Power Co. (2,200 ft.) ,, just below ,, ,,
Electric Railways- - - - - - - - - - -

Mechanical Engineers 1906.

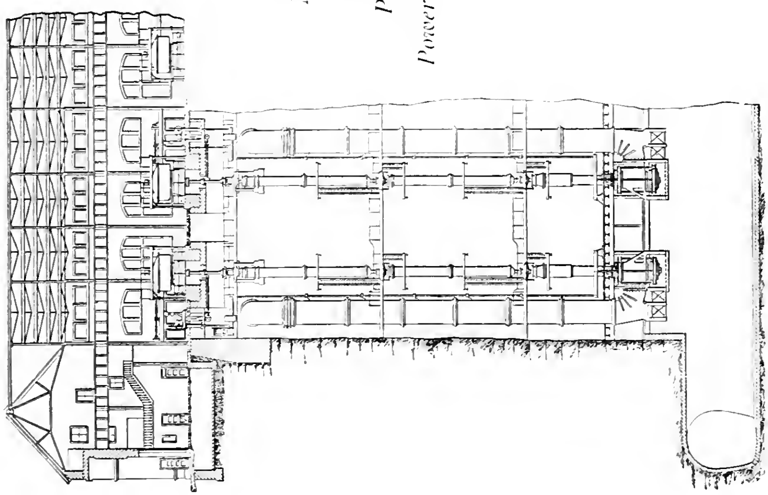
Pl. 5.

5,000 H.P. Twin Outward-flow Turbines.

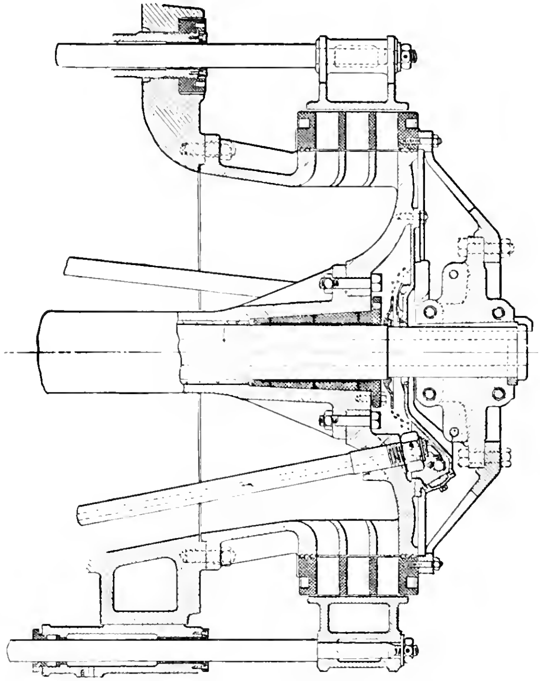


The Niagara Falls Power Co. Power-House No. 1.

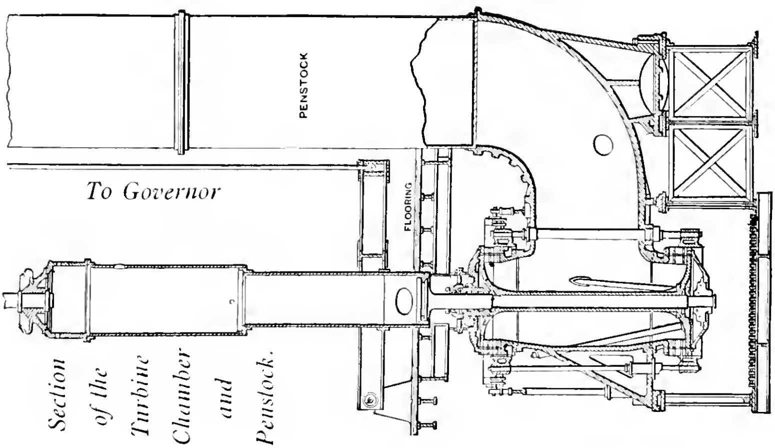
Partial Longitudinal Section of House and Wheel-Pit.



The Niagara Falls Power Co.
5,000 H.P. Twin Outward-flow Turbine.



Vertical Section through Lower Turbine showing cylindric sluice.

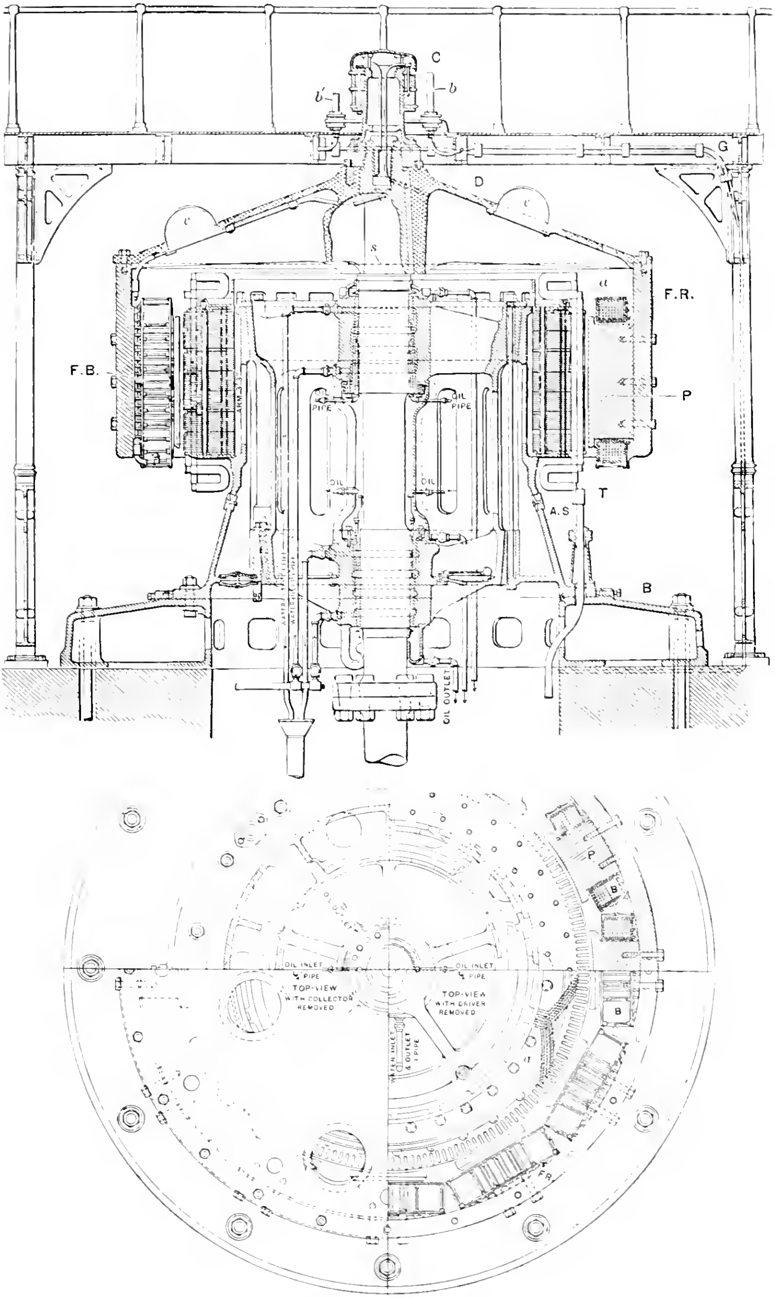


Section of the Turbine Chamber and Penstock.

NIAGARA FALLS POWER-STATIONS. *Plate 7.*

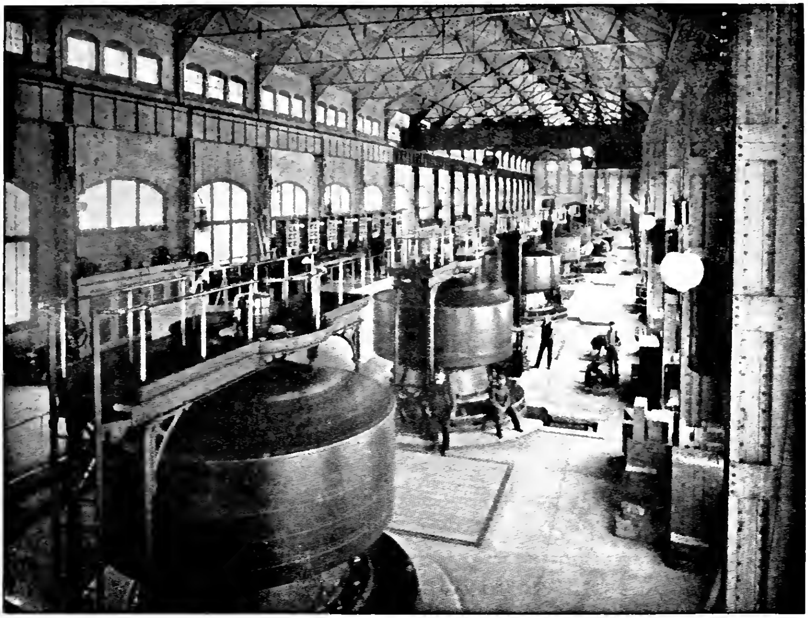
The Niagara Falls Power Co.

Vertical Section through one of the 5,000 H.P. Generators.

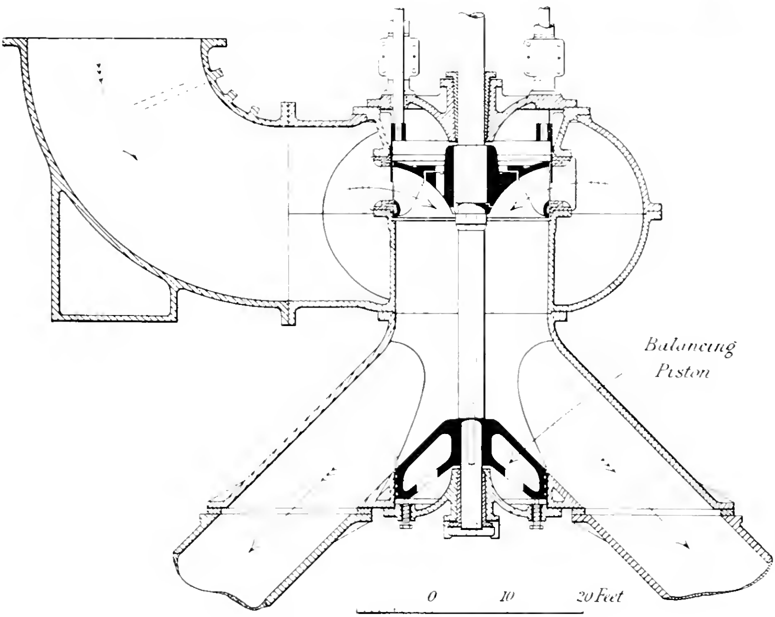


The Niagara Falls Power Co., Power House No. 2.

Generators.

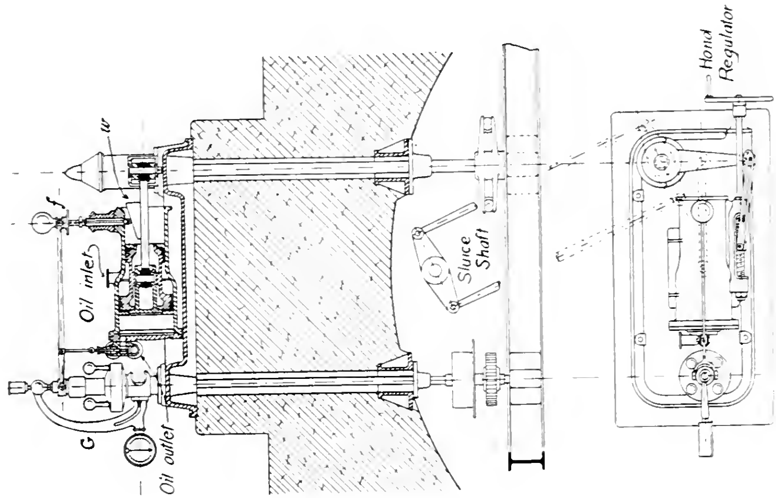


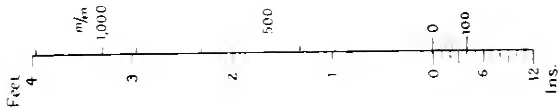
Section of Inward-flow Turbines.



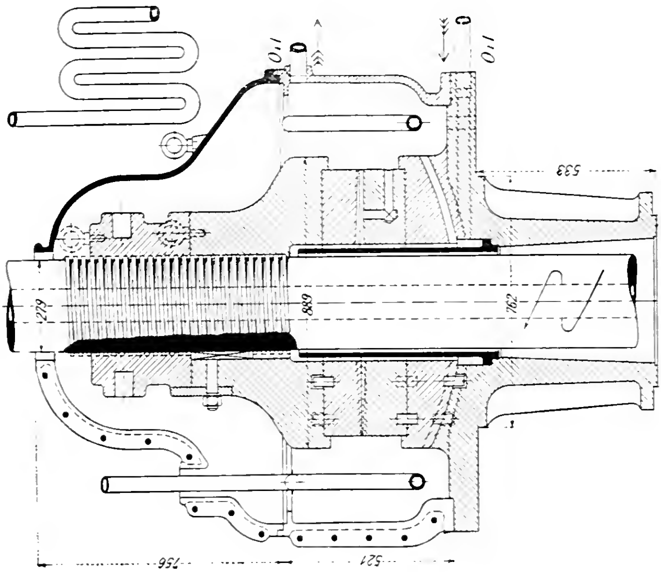
The Niagara Falls Power Co. Power-House No. 2.

Governor.





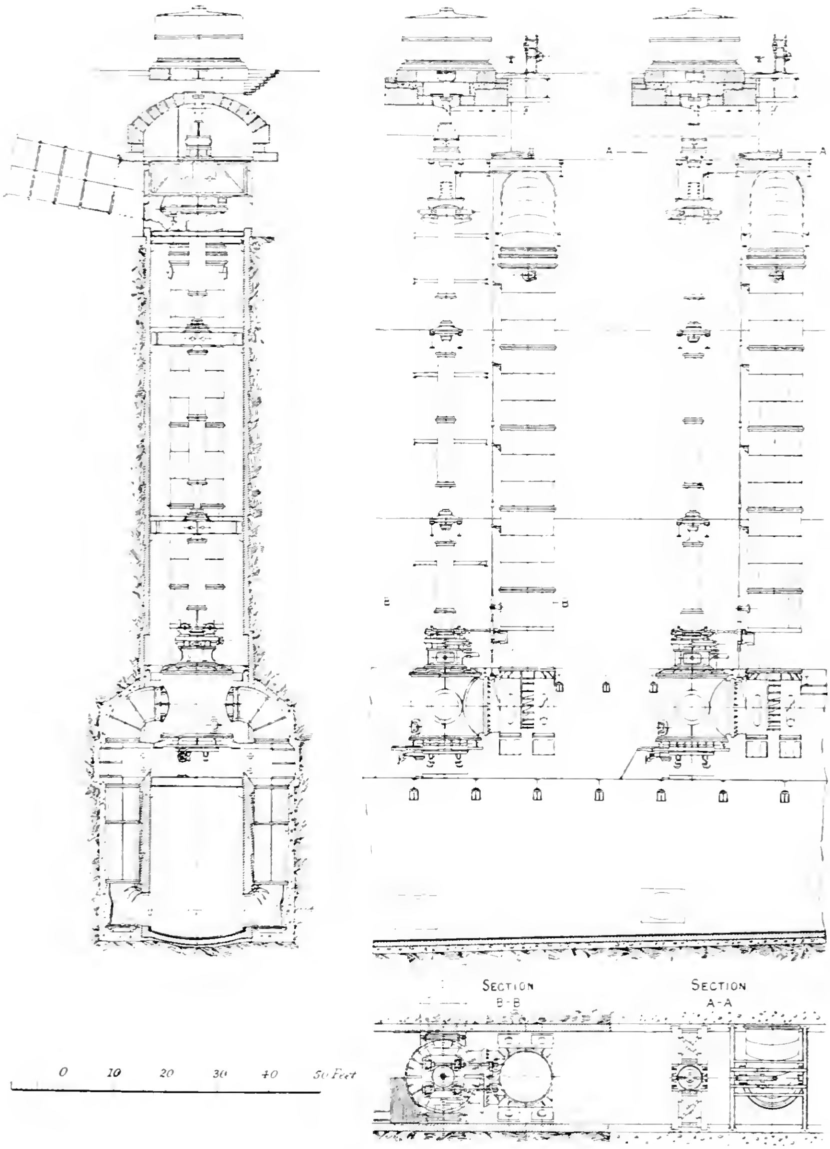
Collar Thrust Bearing.



NIAGARA FALLS POWER-STATIONS. *Plate 10.*

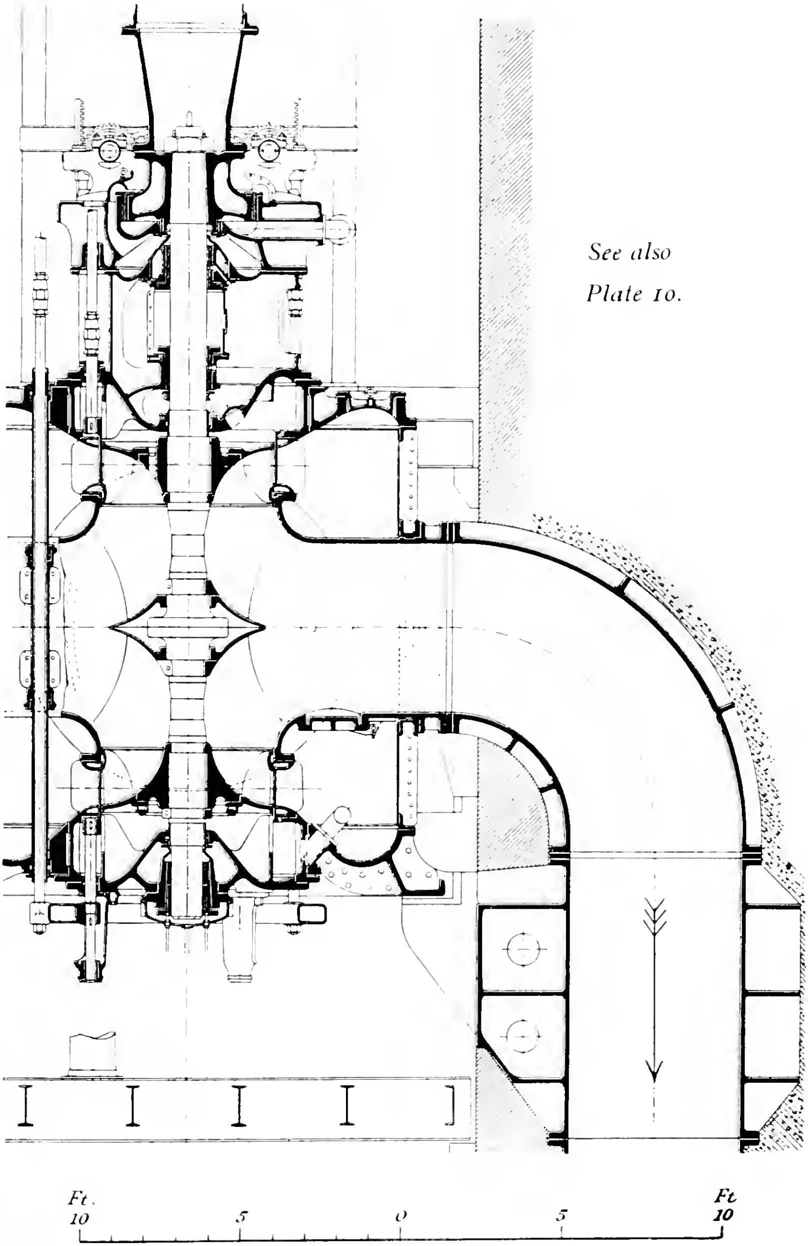
The Canadian Niagara Power Co.

10,000 H.P. Twin Inward-flow Turbines.



The Canadian Niagara Power Co.

Cross Section of 10,000 H.P. Twin Inward-flow Turbines.



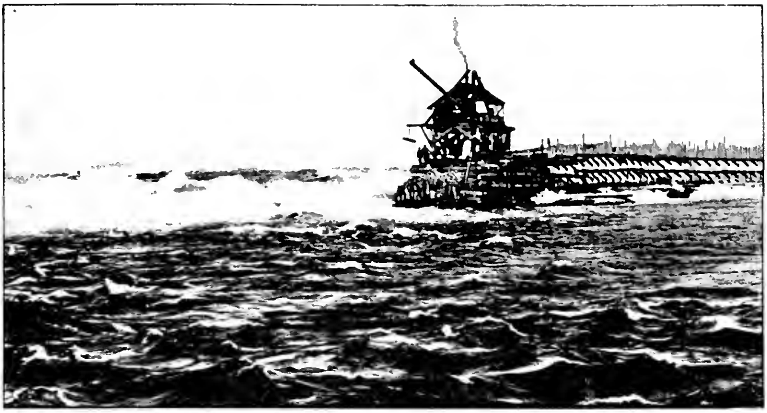
The Canadian Niagara Power Co.

Wheel Slot looking North.

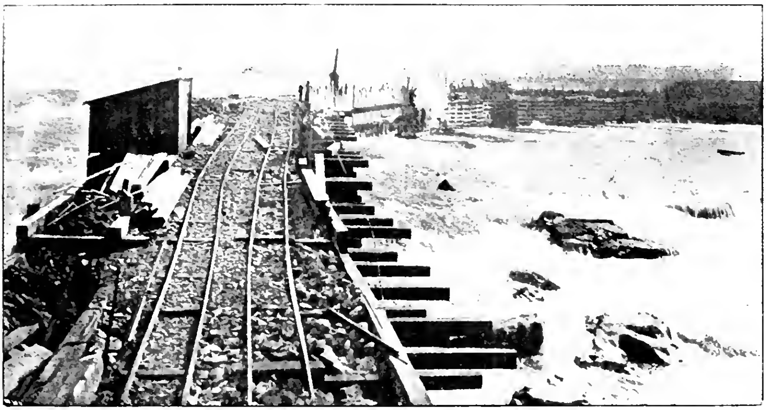
165 feet deep, 18 feet wide inside of brick lining, and 570 feet long.

The Electrical Development Co. of Ontario.

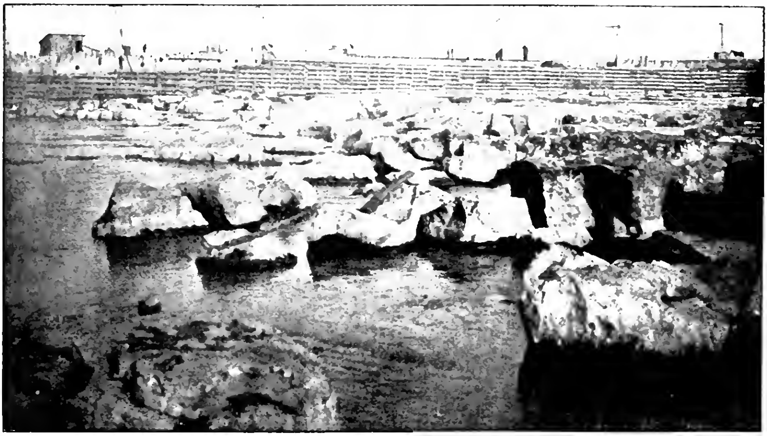
Main Coffer-Dam just below the second cascade.



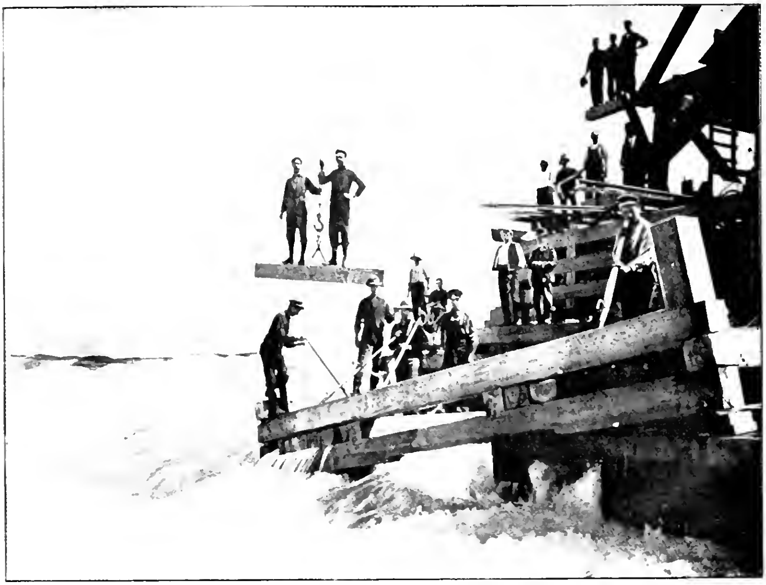
Main Coffer-Dam showing form of Construction.



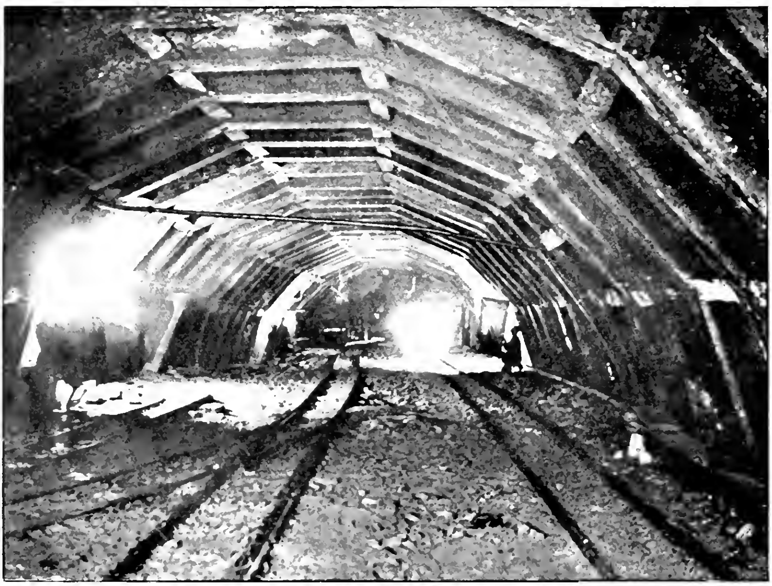
Showing successful unwatering of Cascade rapids between the main and subsidiary Coffer-Dams



The Electrical Development Co. of Ontario.
Cascade and Launching of a Crib.

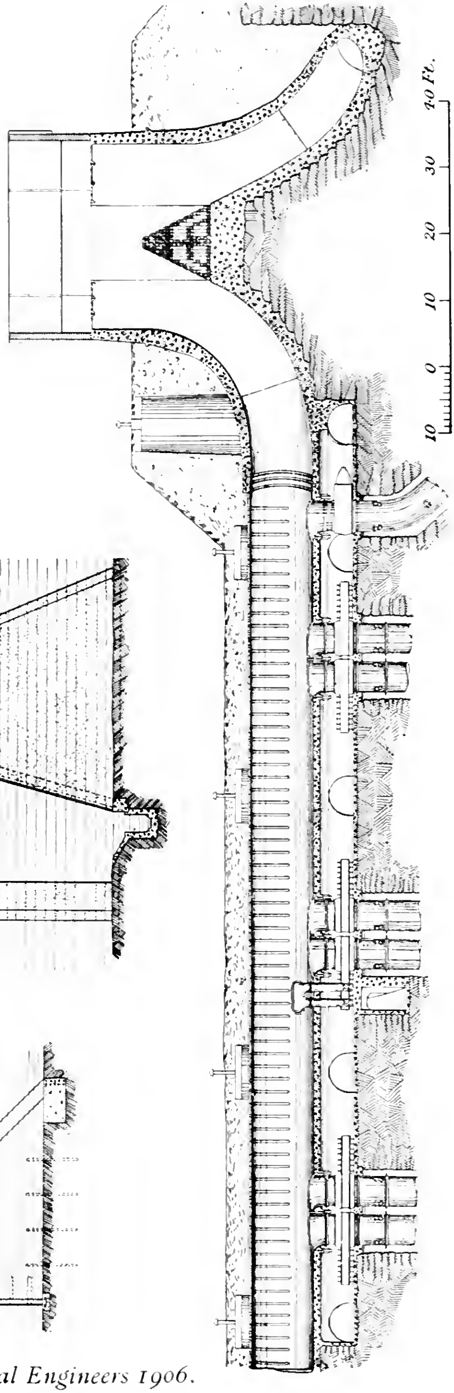


Portal end of Tunnel beneath the Falls showing Timbering, etc., excavated to Springing.

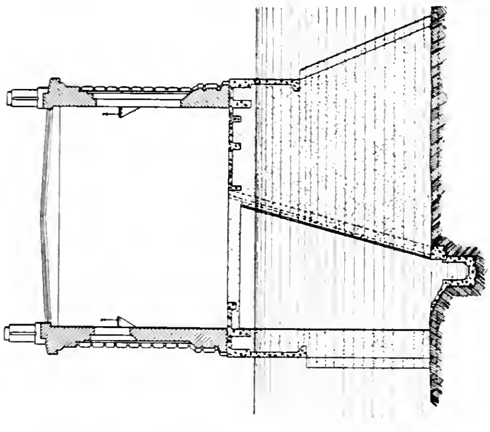


The Ontario Power Co.

Section through Valve Chamber and Helical Spillway.

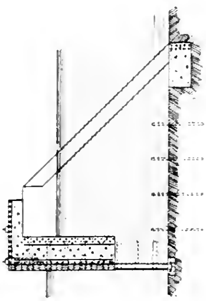


Section through Screen House.



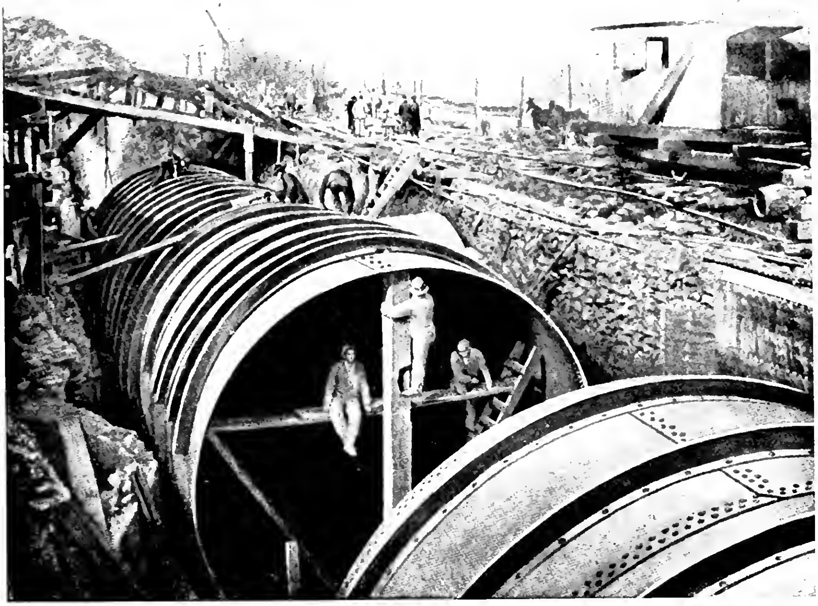
Section through Intake.

This is nearly 600-ft. long. A concrete curtain-wall extends down 9-ft. into the water, here 15-ft. deep.



The Ontario Power Co.

First of 3 Main Conduits, 18' 0" and 20' 0" diam. during construction.

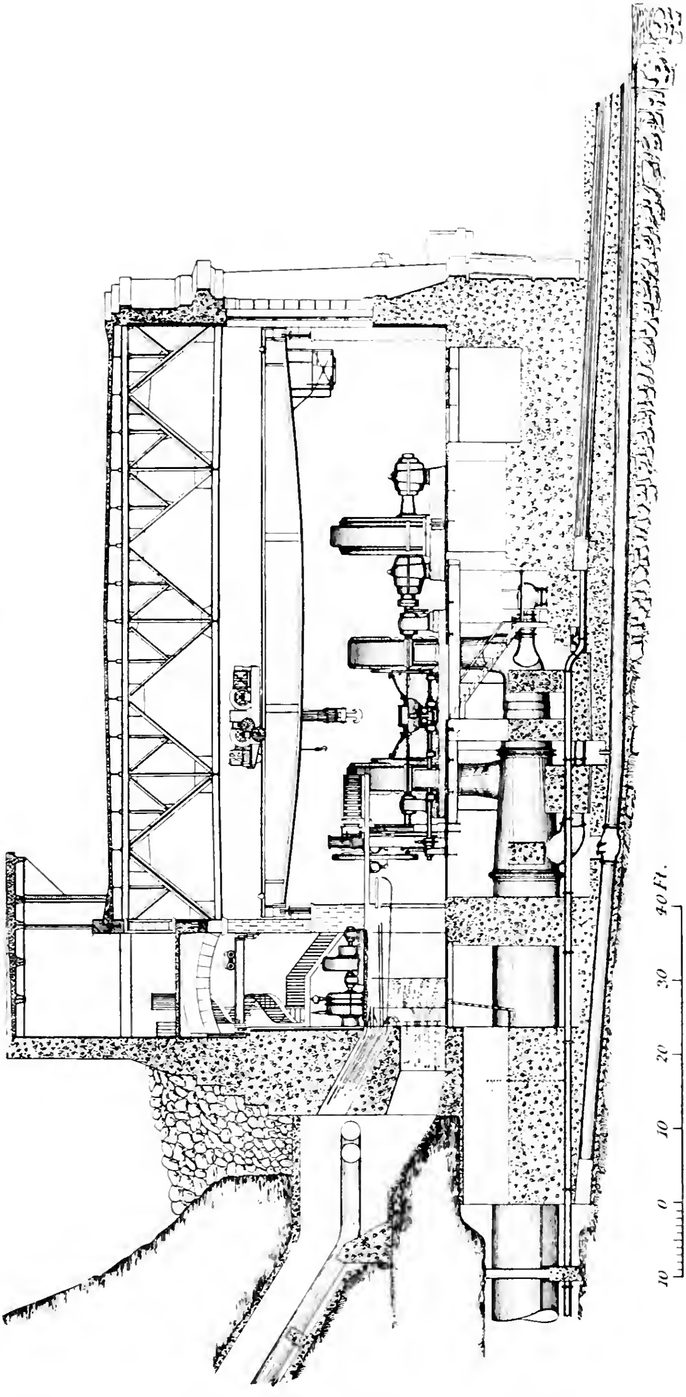


Showing Concrete Envelope.

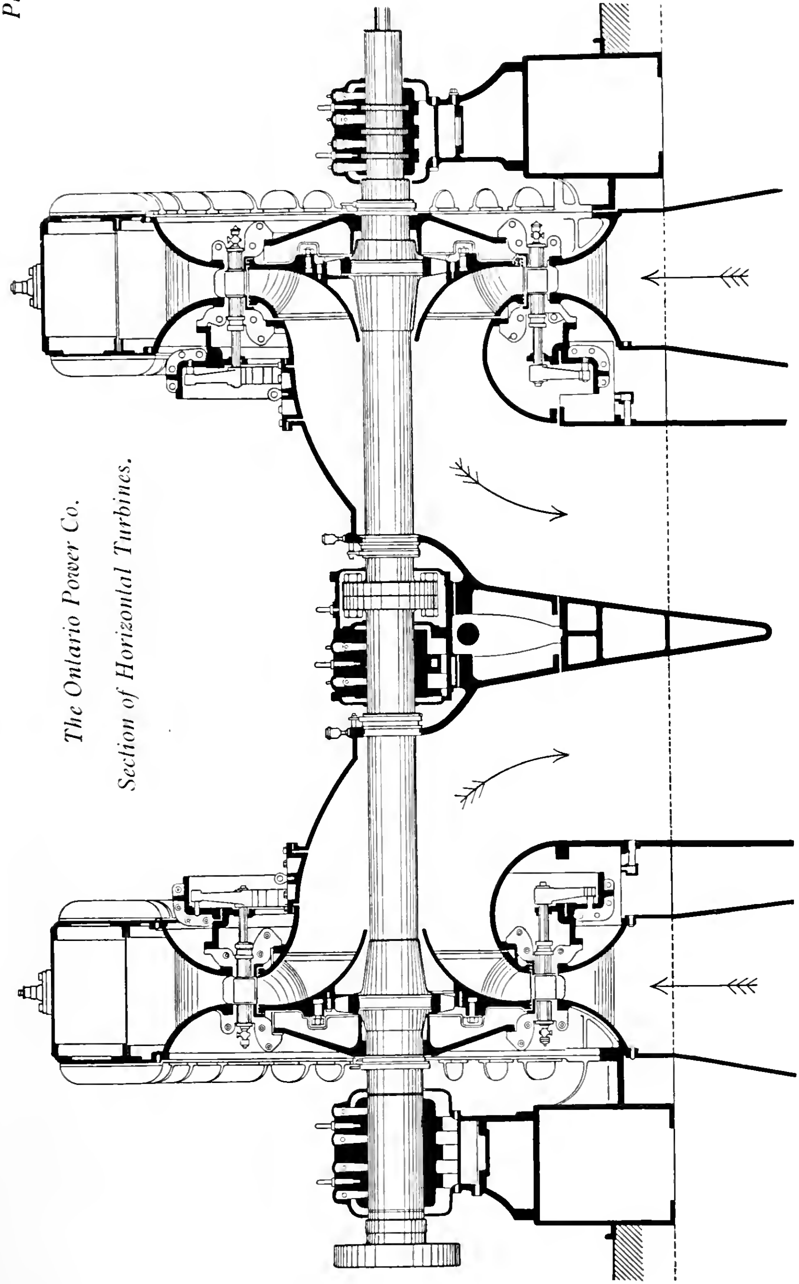
Pl. 17.

The Ontario Power Co.

Cross-Section of Generating Station.



Mechanical Engineers 1906.



The Ontario Power Co.

Section of Horizontal Turbines.

Fig. 1. *Mallet Compound.—Baltimore and Ohio.*

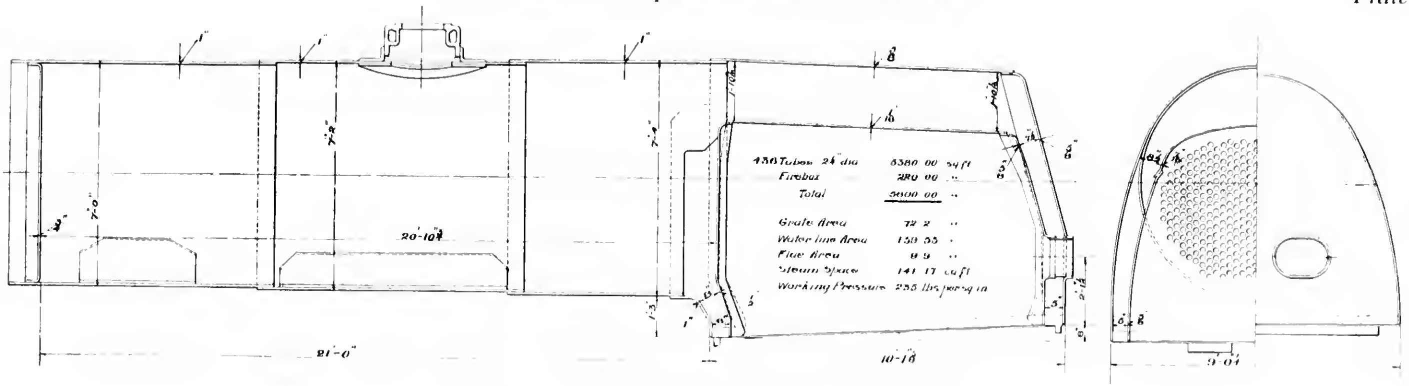
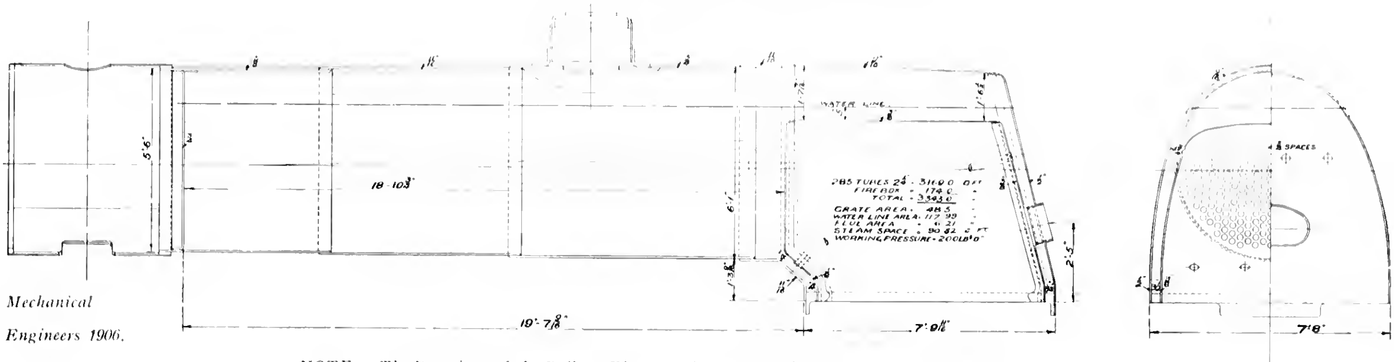


Fig. 2. *Lake Shore and Michigan Southern.*



NOTE:—The Drawings of the Boilers (Figs. 1 to 27) are all to the same scale.—1 inch = 6 feet.

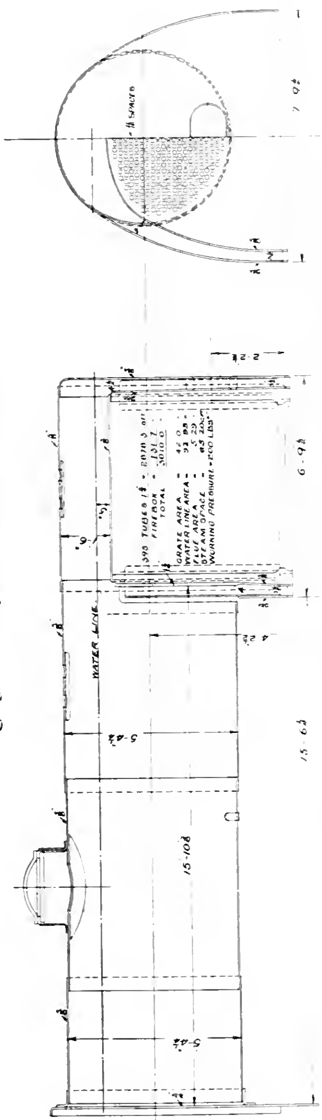


Fig. 3. *Decapod.—Great Eastern.*

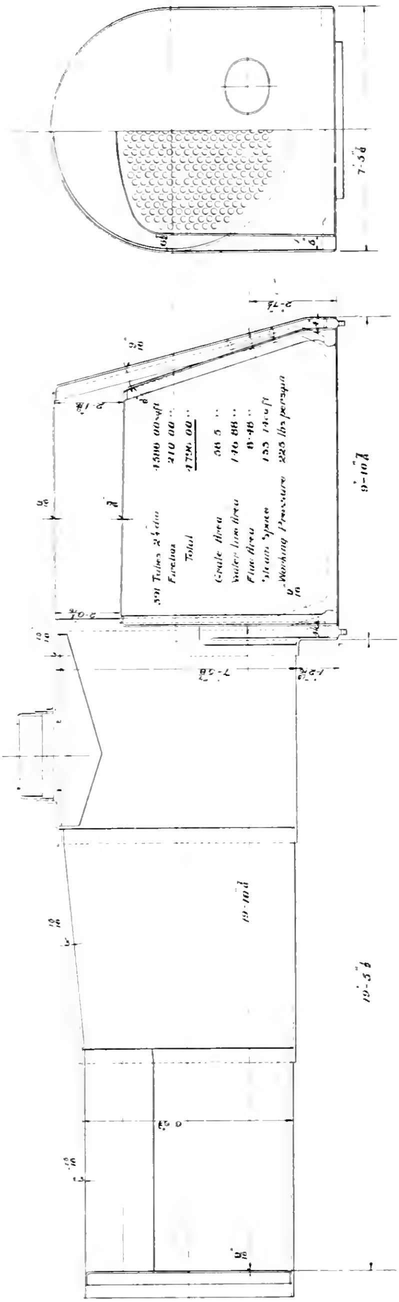


Fig. 4. 2—10—2 *Tandem Compound.—Atchison-Topeka and Santa Fé.*

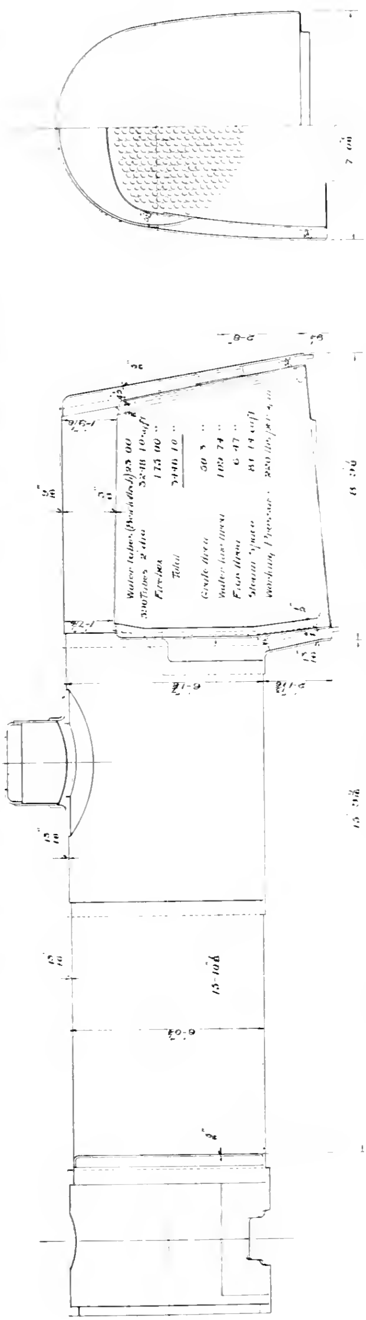


Fig. 5. Cole 4 Cylinder Compound.—New York Central and Hudson River.

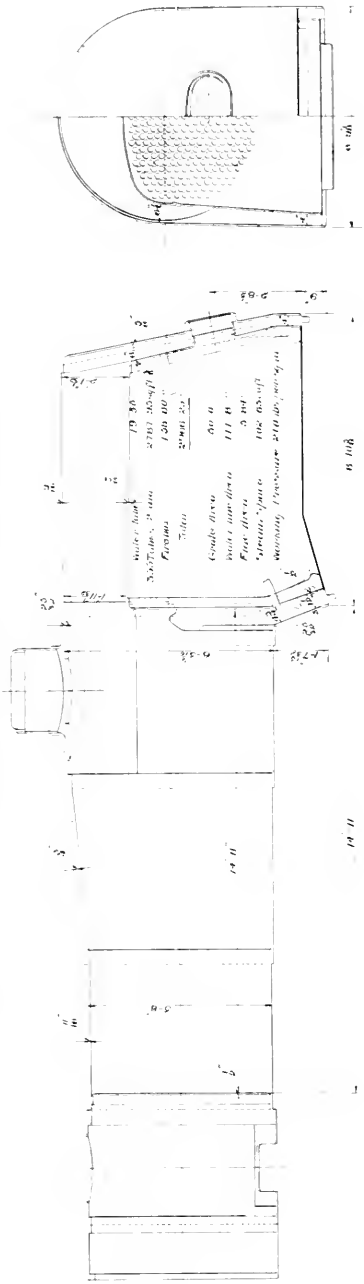


Fig. 6. 2—8—0 Tandem Compound.—Colorado and Southern.

Plate 22.

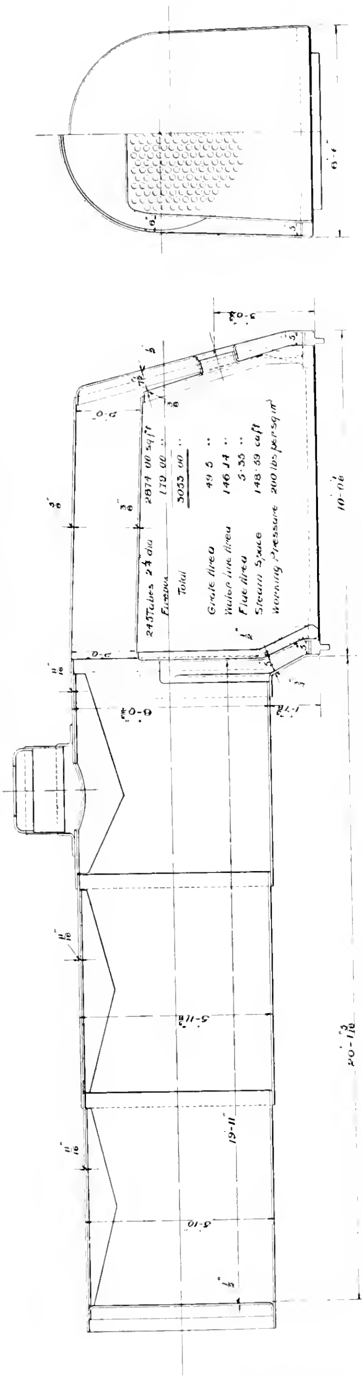


Fig. 7. 4—6—2 Type.—Chicago and Alton.

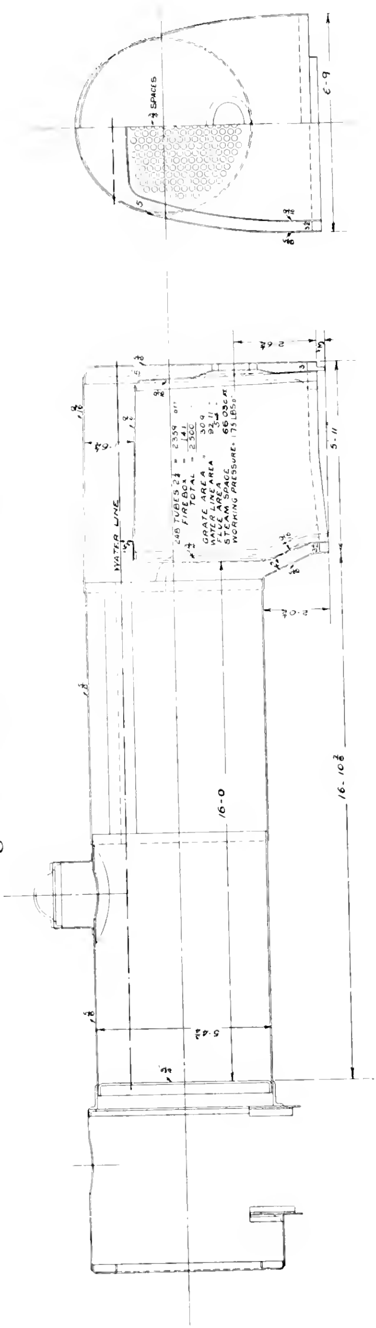


Fig. 8. "Atlantic."—Great Northern.

Plate 23.

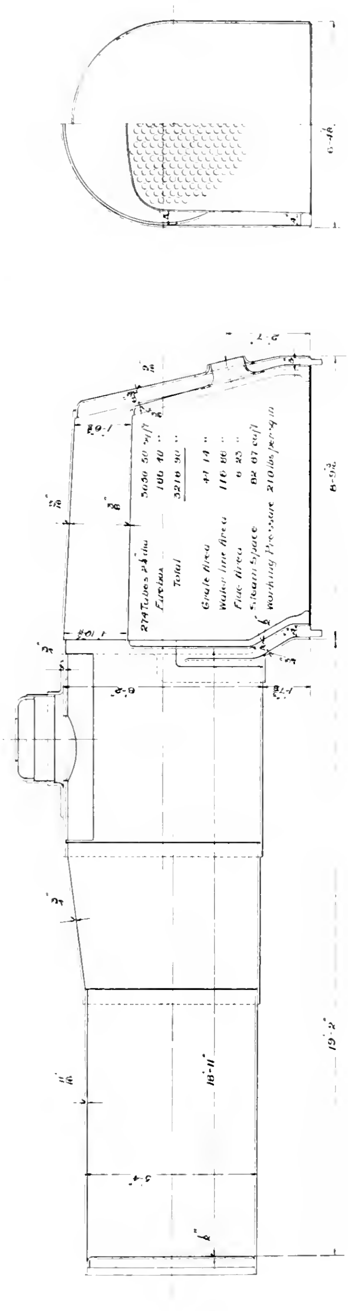


Fig. 9. Baldwin 4-Cylinder Compound.—Chicago, Burlington and Quincy.

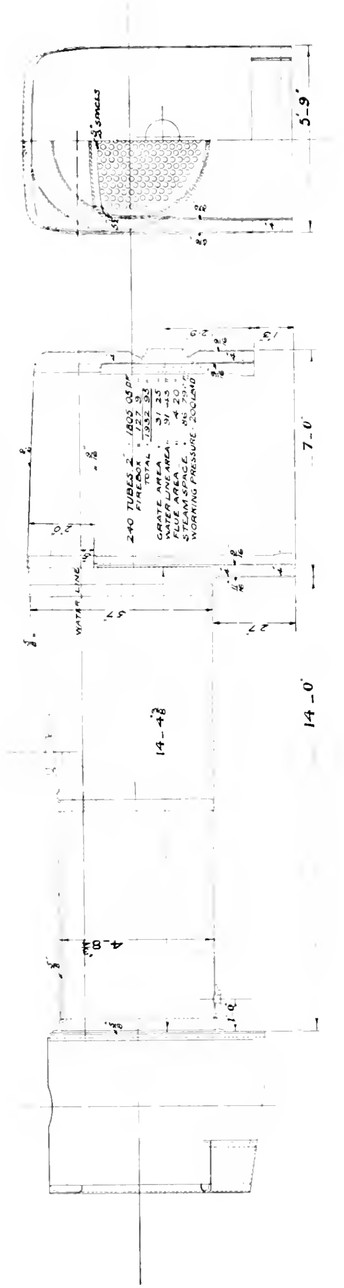


Fig. 10. Lot 116.—Great Western.

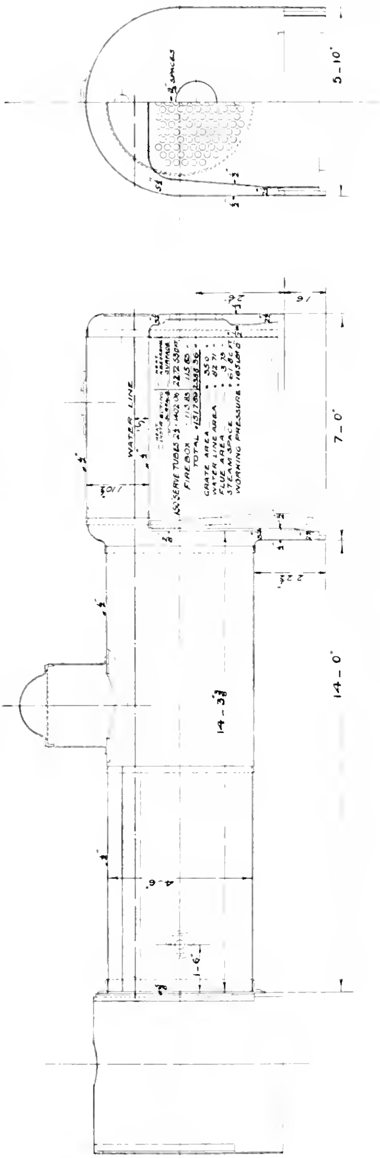


Fig. 11. No. 36.—Great Western.

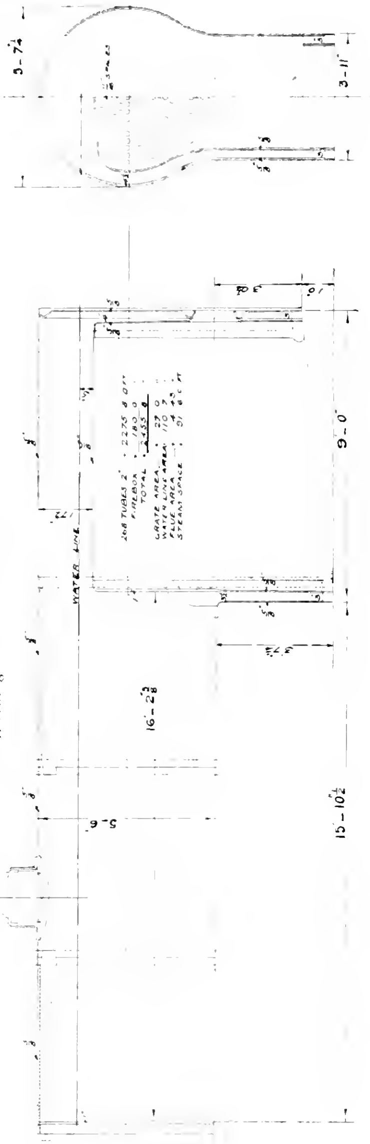


Fig. 12. North Eastern.
Working Pressure 200 lbs.

Fig. 13. North Eastern.

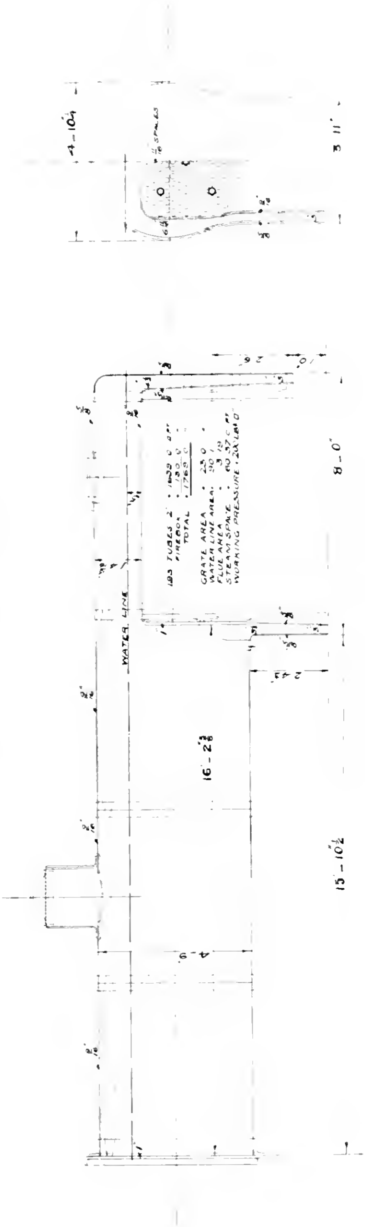


Fig. 14. No. 1.—Great Western.
(For Details of Boiler see Fig. 29, Plate 33; and Photo. Fig. 30, Plate 31).

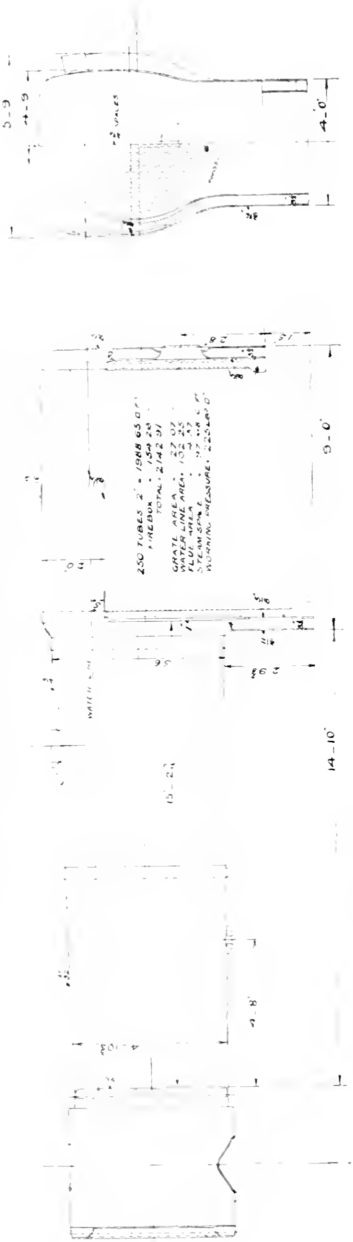


Plate 26.

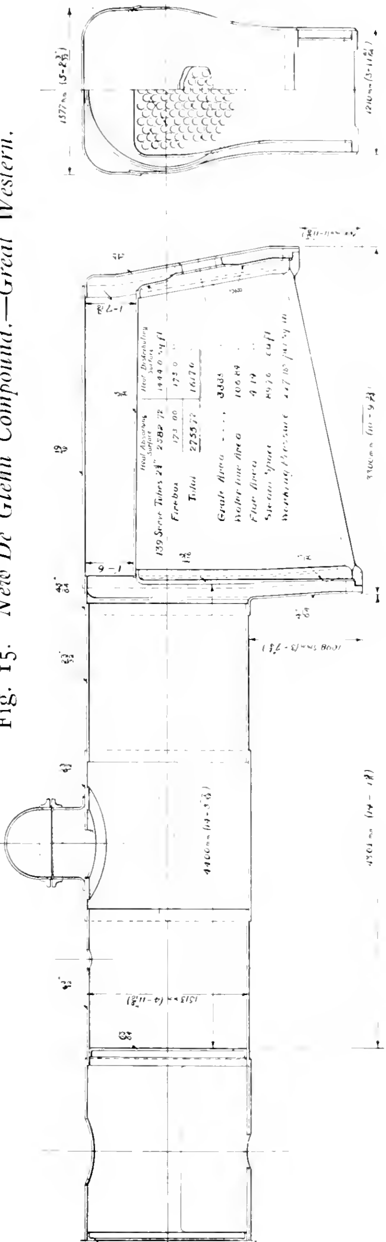


Fig. 15. New De Glehn Compound.—Great Western.

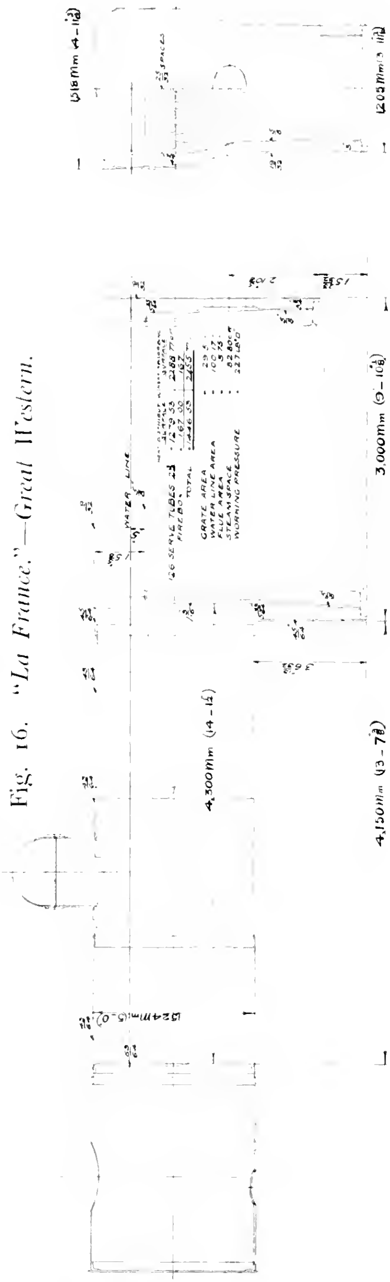


Fig. 16. "La France."—Great Western.

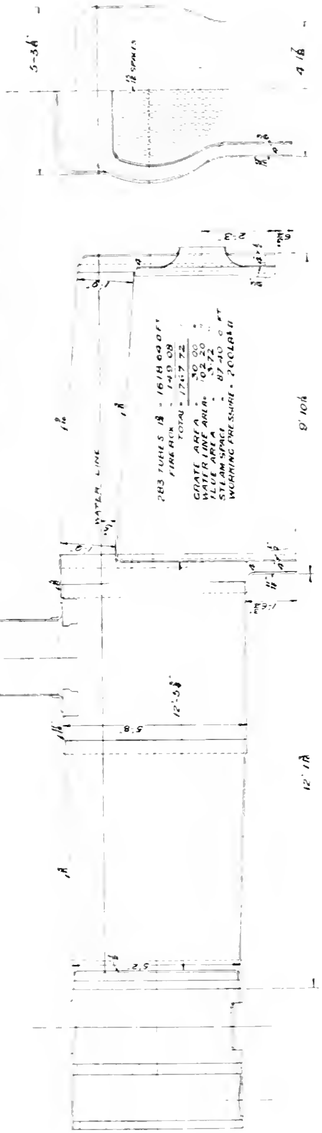


Fig. 17. Chicago, Burlington and Quincy.

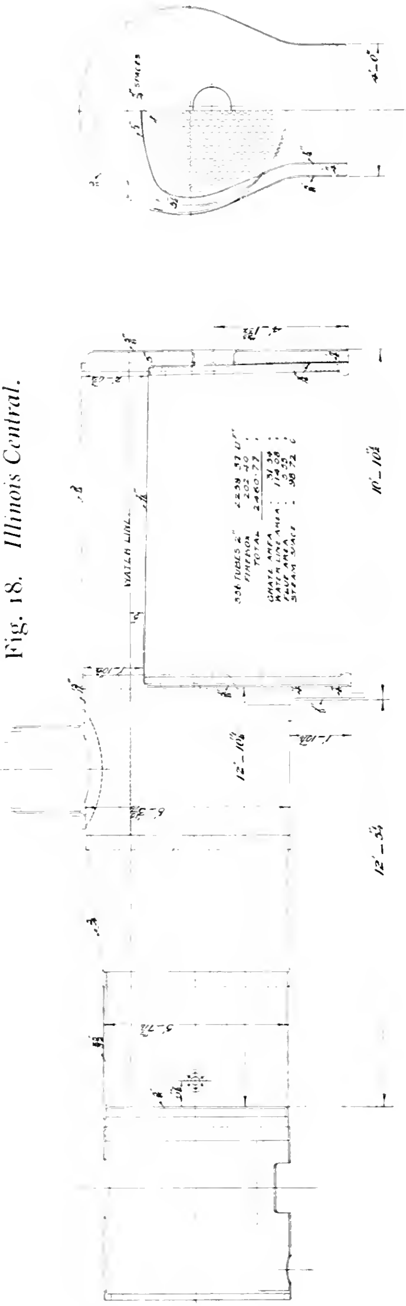


Fig. 18. Illinois Central.

Plate 28.

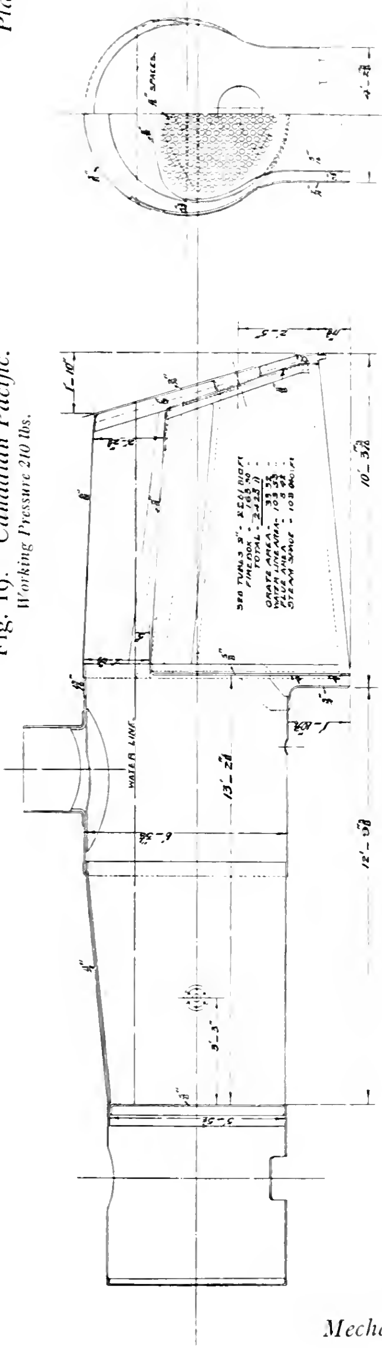


Fig. 19. *Canadian Pacific.*
Working Pressure 210 lbs.

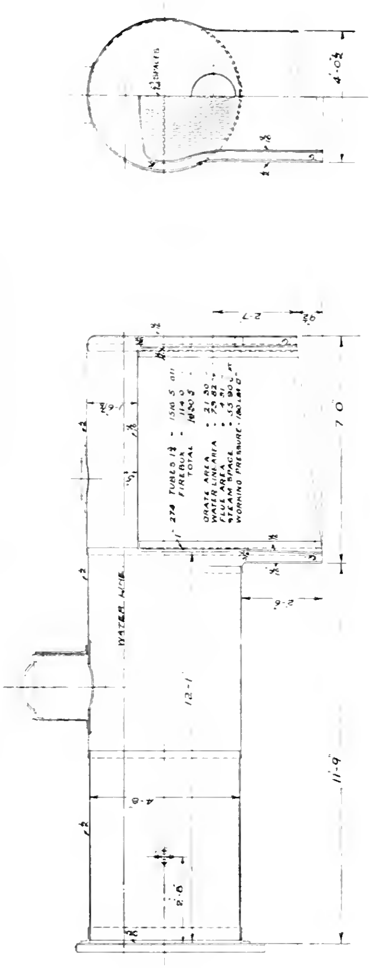


Fig. 20. *Great Eastern. (Passenger and Goods.)*

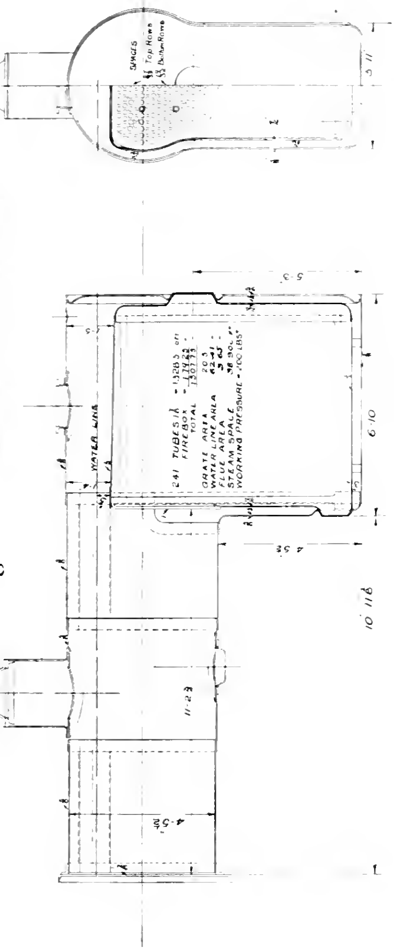


Fig. 21. London and North Western.

(The 1906 Express L. and N. W. Boiler is referred to and illustrated in the discussion.)

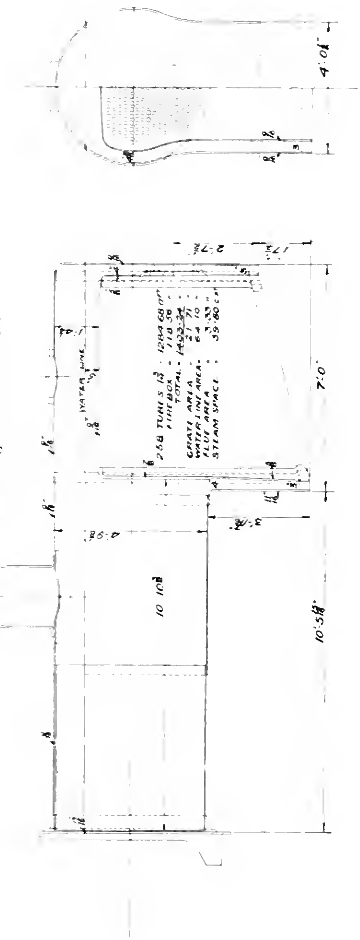


Fig. 22. Midland.

Working Pressure 175 lbs.

Plate 30.

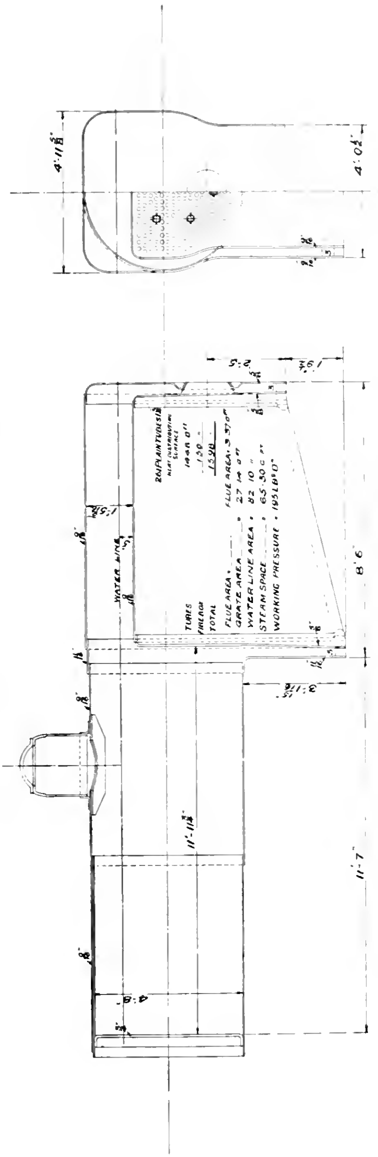


Fig. 23. Compound.—Midland.
Fitted with Plain Boiler Tubes (Serve Tubes not in use now).

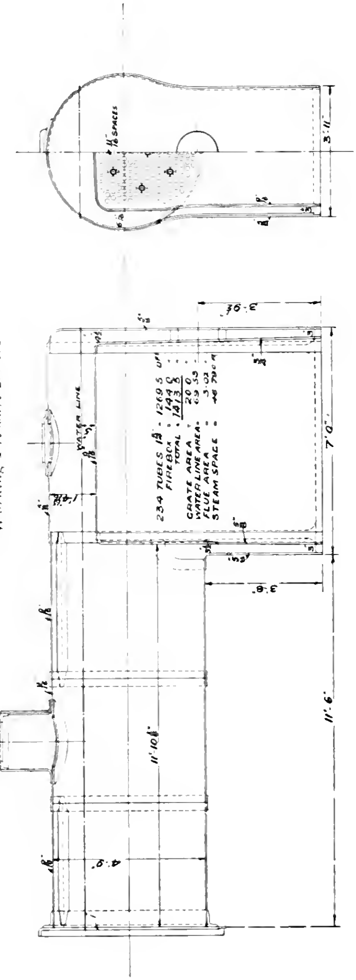


Fig. 24. North Eastern.
Working Pressure 200 lbs

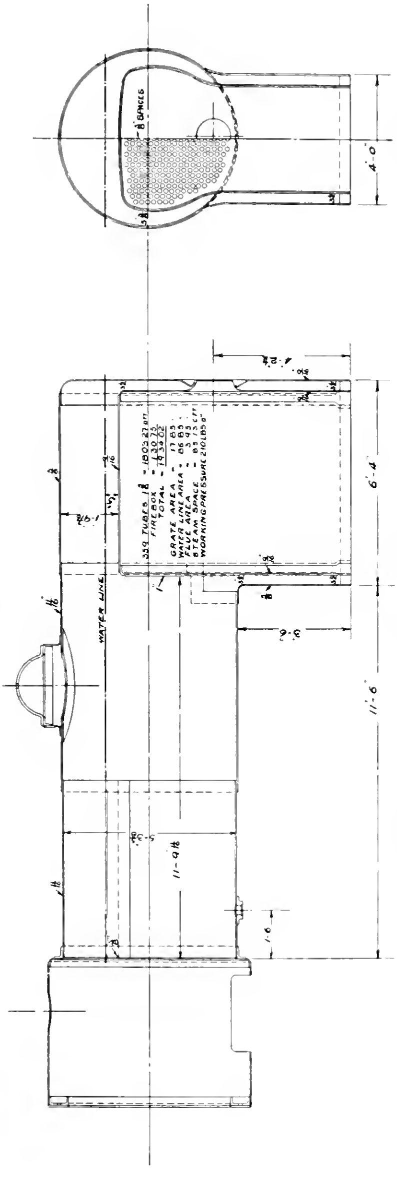


Fig. 25. "Cawdor".—Great Western.

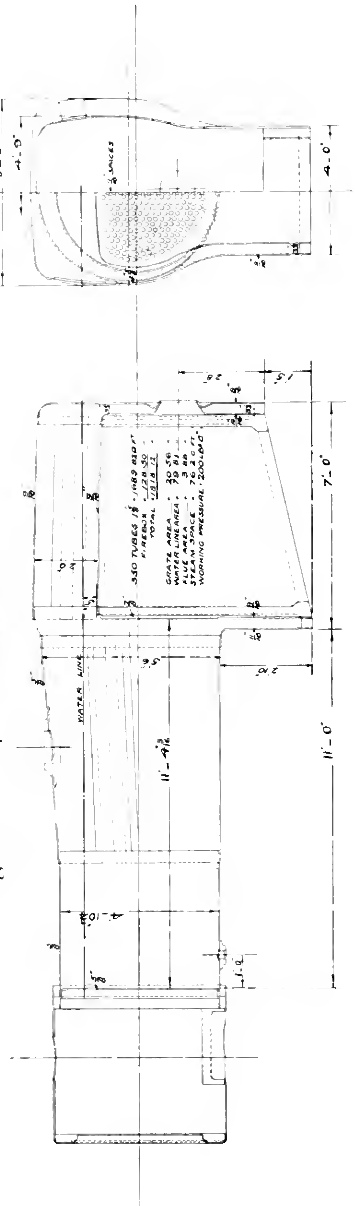


Fig. 20. No. 4.—Great Western.

Plate 32.

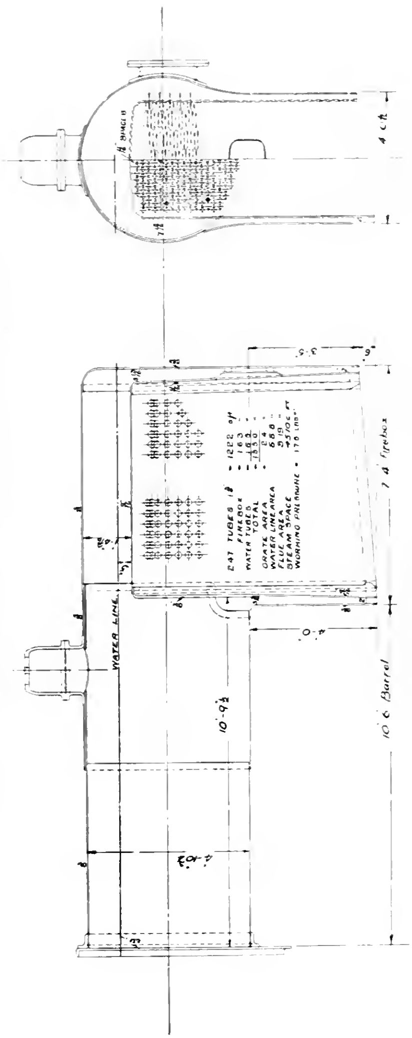


Fig. 27. *Water Tube.—London and South Western.*

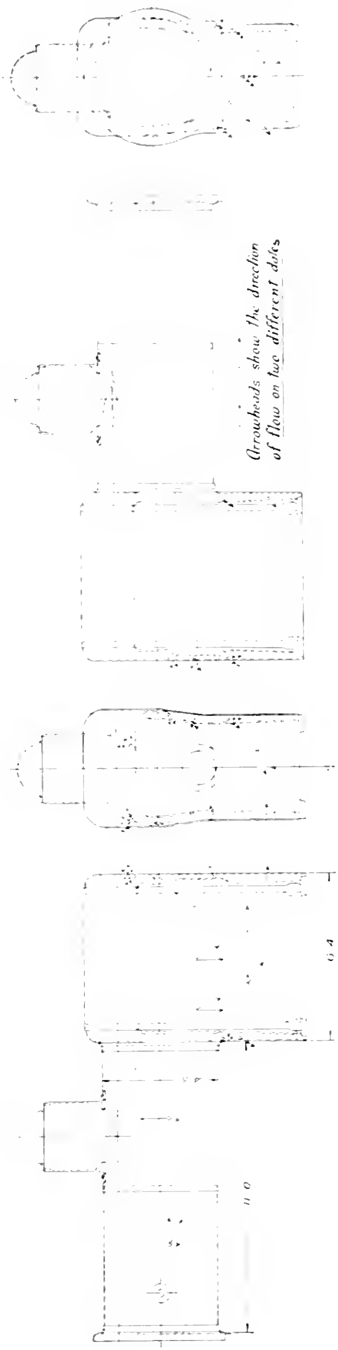


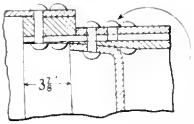
Fig. 28. *Circulation of Water with 2 different methods of Firing.*

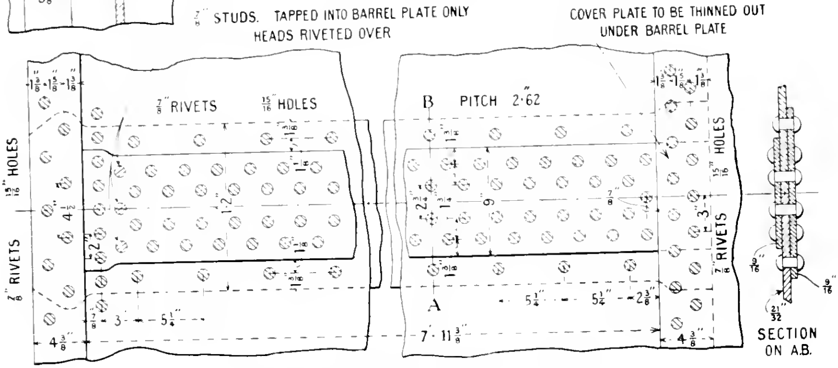
Fig. 29.

Boiler Details.—Great Western.

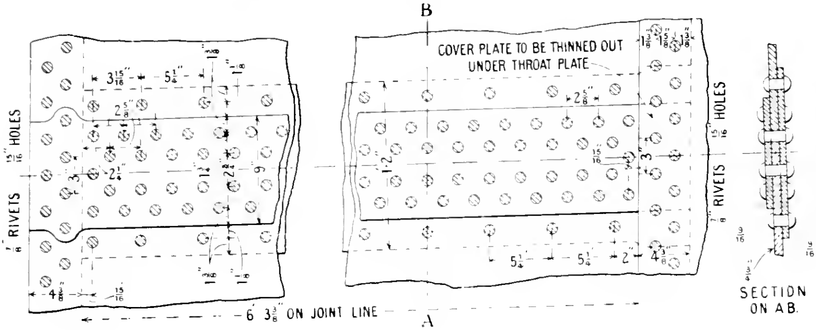
Standard Boiler, No. 1. June, 1902.

(See Fig. 14, Plate 25; Fig. 30, Plate 34; and Table 1.)

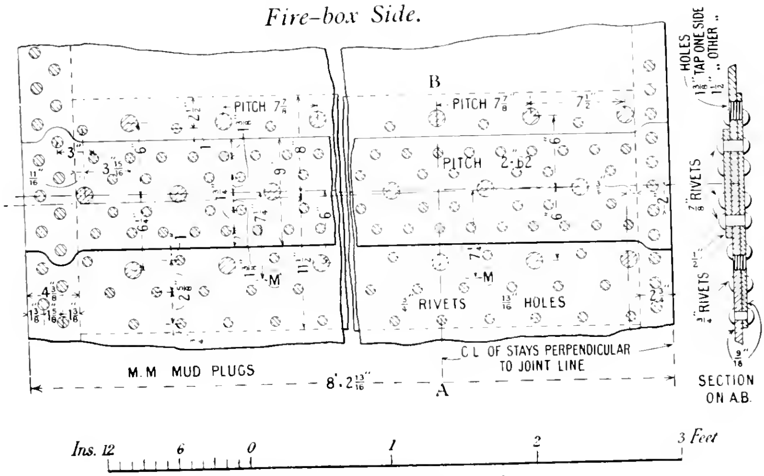




Longitudinal Butt Joints.—Barrel.



Fire-box Side.



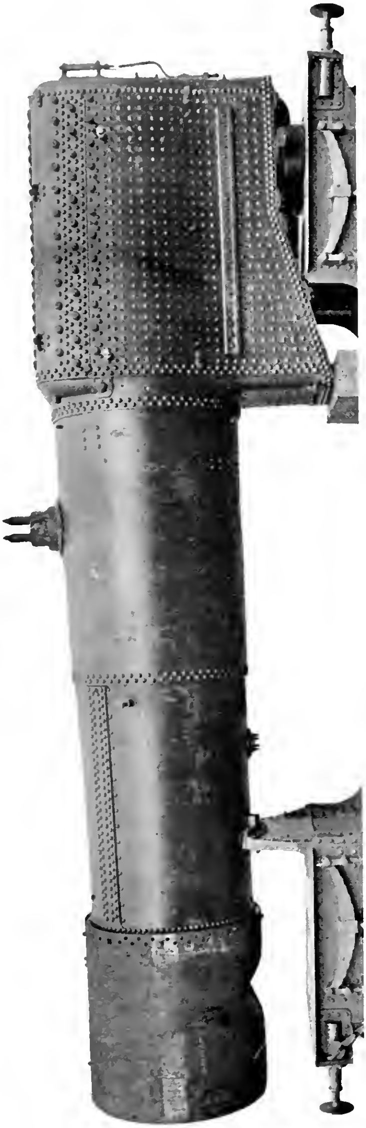


Fig. 30. *Standard Boiler, No. 1. Great Western.*

See also Plates 25 and 33; and Table 1.

(*Mr. George Hughes remarks.*)

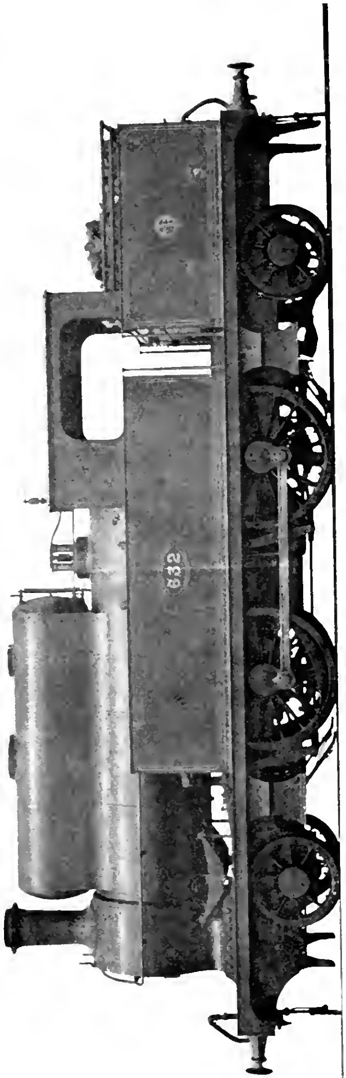
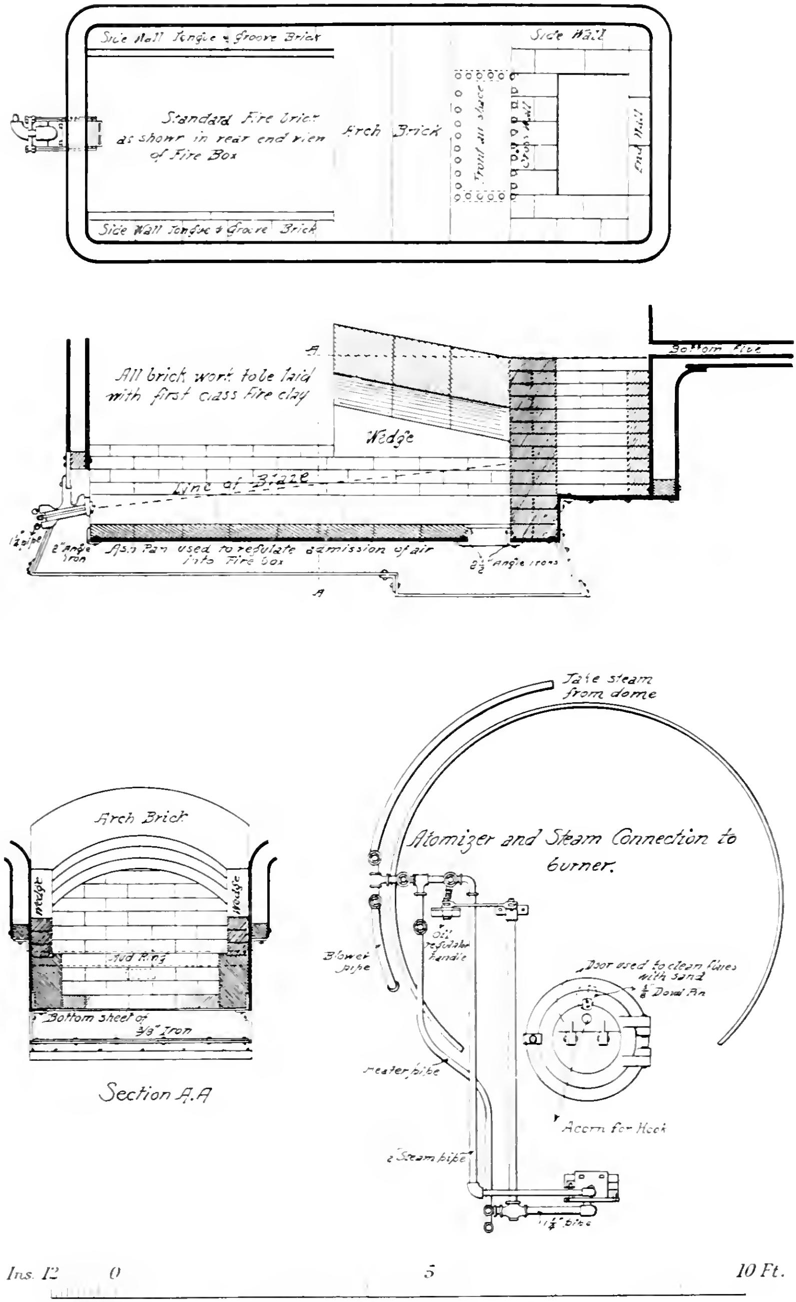


Fig. 35. *Tank-Engine L. and Y. fitted with Thermal Storage System. (Halpin.)*

See also Figs. 31 and 16 in letterpress.

National Railway of Tehuantepec.

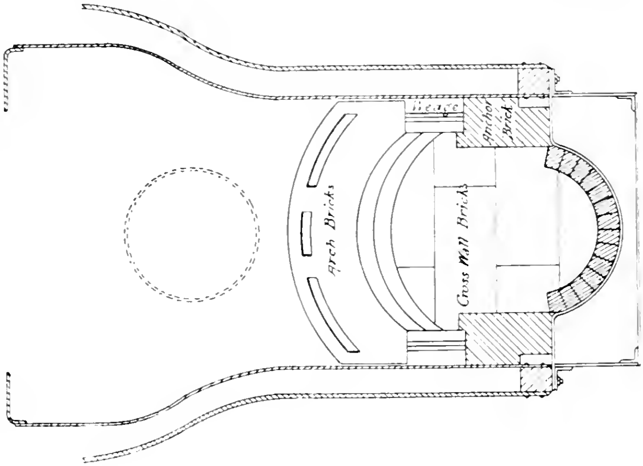
Fig. 1. *Fire-box, Inside dimensions Brick lining 9′ 0″ × 3′ 6″, with Oil and Steam Connections.*

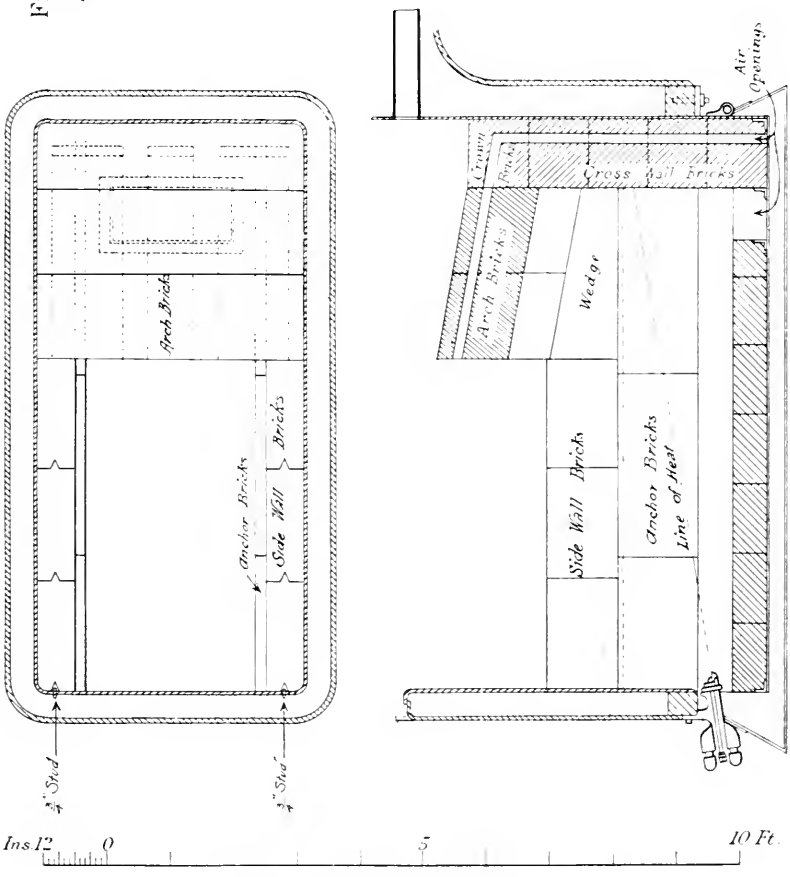


National Railway of Tehuantepec. Plate 36.

Fig. 2. Oil Fuel Arrangement in Locomotive Fire-boxes, Inside Dimensions 9' 0" × 4' 3".

Section of Brickwork with Invert Arch.





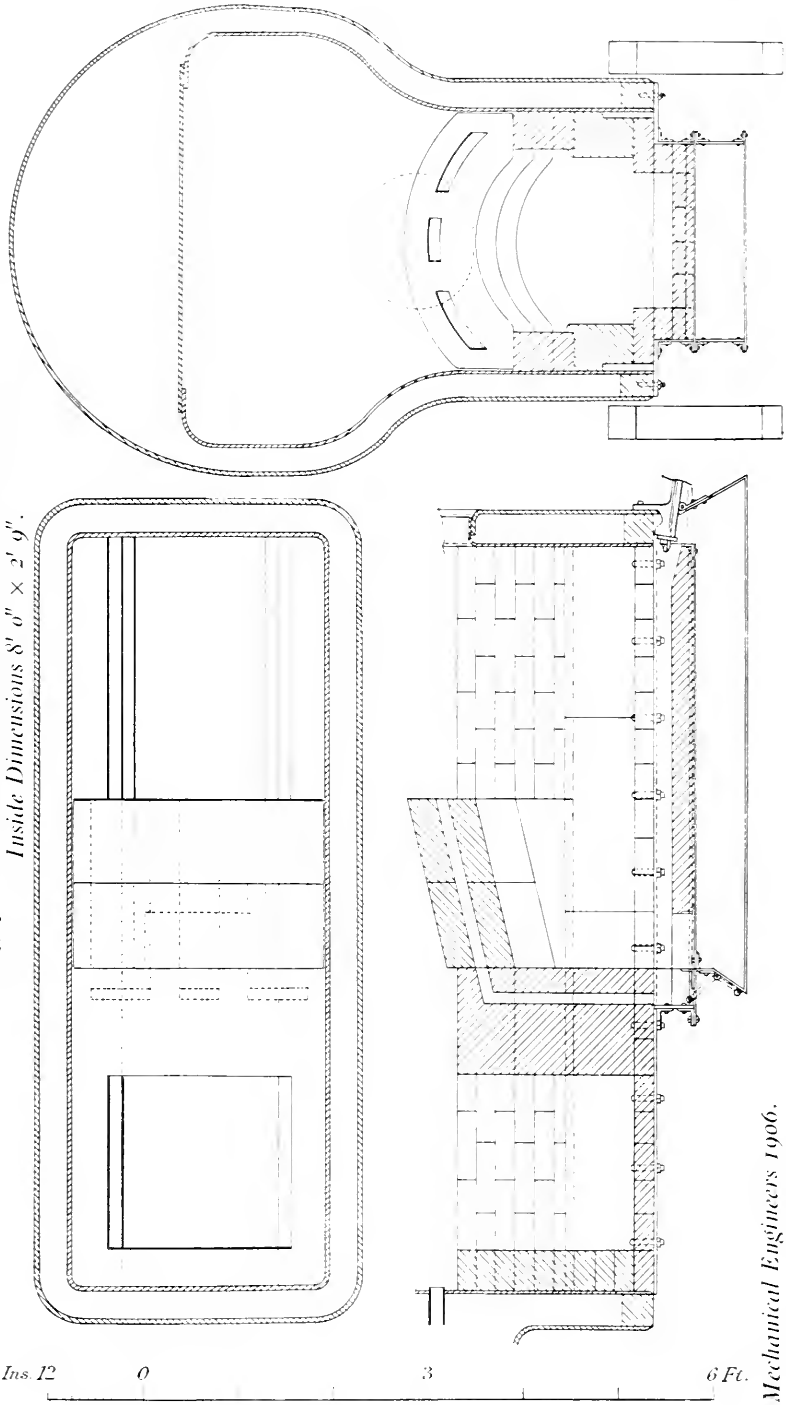


Fig. 3. National Railway of Tehuantepec.
Oil Fuel Arrangement in Locomotive Fire-boxes,
Inside Dimensions 8′ 0″ × 2′ 9″.

National Railway of Tehuantepec.

Fig. 4. *Oil and Steam Connections between Engine and Tender.*

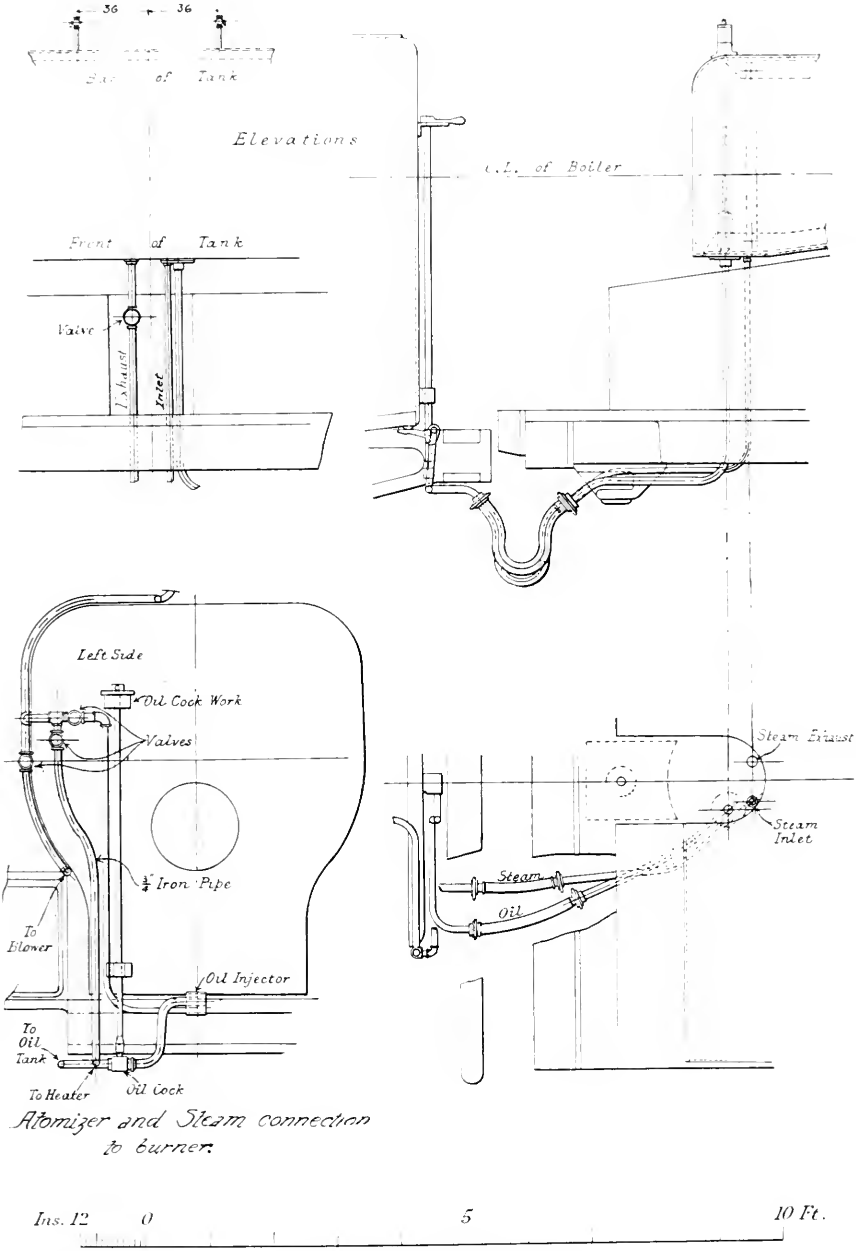
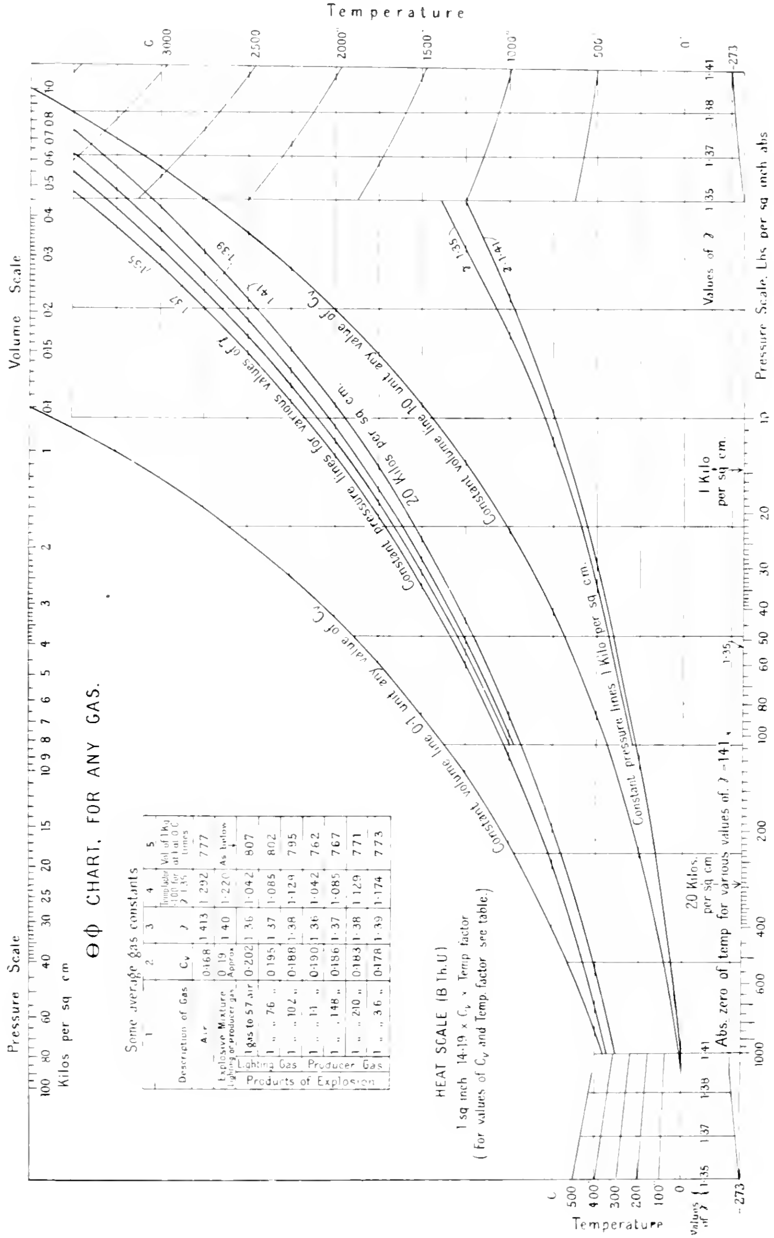


Fig. 1.

θφ Chart, for any Gas.



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Engineers, London
Proceedings